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VOLUME X.

GEOLOGICAL SURVEY OF OHIO

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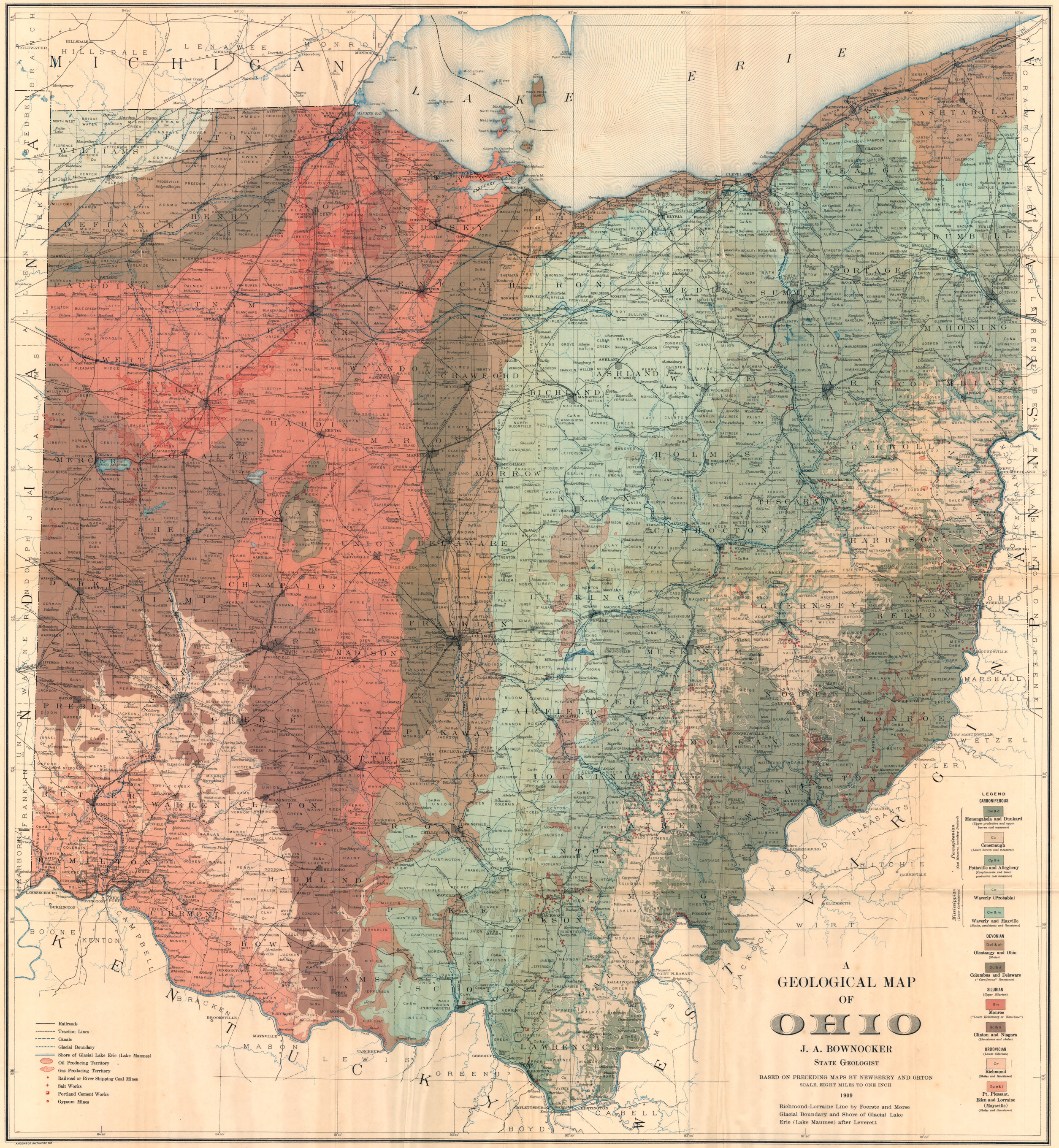
A GEOLOGICAL MAP OF OHIO
J. A. BOWNOCKER
STATE GEOLOGIST
BASED ON PRECEDING MAPS BY NEWBERRY AND ORTON
SCALE, EIGHT MILES TO ONE INCH
1909
Richmond-Lorraine Line by Foerste and Morse
Glacial Boundary and Shore of Glacial Lake Erie (Lake Maumee) after Leverett
LEGEND
CARBONIFEROUS
Cm&d Monongahela and Dunkard (Upper productive and upper barren coal measures)
Cc Conemaugh (Lower barren coal measures)
Cp&a Pottsville and Allegheny (Conglomerate and lower productive coal measures)
Pennsylvanian (Coal Measures, including Dunkard)
Cw Waverly (Probable)
Cw&m Waverly and Maxville (Shales, sandstones and limestones)
Mississippian (Lower Carboniferous)
DEVONIAN
Dol&oh Olentangy and Ohio (Shales)
Dc&d Columbus and Delaware ("Corniferous" limestones)
SILURIAN (Upper Silurian)
Sm Monroe ("Lower Helderberg or Waterlime")
Sc&n Clinton and Niagara (Limestones and shales)
ORDOVICIAN (Lower Silurian)
Or Richmond (Shales and limestones)
Op.e&l Pt. Pleasant, Eden and Lorraine (Maysville) (Shales and limestones)
Railroads
Traction Lines
Canals
Glacial Boundary
Shore of Glacial Lake Erie (Lake Maumee)
Oil Producing Territory
Gas Producing Territory
Railroad or River Shipping Coal Mines
Salt Works
Portland Cement Works
Gypsum Mines
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INDIANA
PENNSYLVANIA
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GEOLOGICAL SURVEY OF OHIO

VOLUME X

Comprising Bulletins 9, 10 and 11 of the Fourth Series

J. A. BOWNOCKER, STATE GEOLOGIST.

COLUMBUS, OHIO, DECEMBER, 1910.

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To Governor Judson Harmon:

Dear Sir:—I present herewith Volume X of the Geological Survey of Ohio, consisting of the following:

Bulletin 9. Coal. By J. A. Bownocker, N. W. Lord and E. E. Somermeier.

Bulletin 10. The Middle Devonian. By Clinton R. Stauffer.

Bulletin 11. The Manufacture of Roofing Tiles. By W. G. Worcester, with the co-operation of Edward Orton, Jr.

Geological Map of Ohio. By J. A. Bownocker.

These bulletins and map have already been given to the public and are assembled in this form to bring them in harmony with the previous volumes, as provided by statute.

Respectfully submitted,

J. A. Bownocker,
State Geologist.

Columbus, December 1, 1910.

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THE SURVEY IN ITS RELATIONS TO THE PUBLIC.

The usefulness of the Survey is not limited to the preparation of formal reports on important topics. There is a constant and insistent desire on the part of the people to use it as a technical bureau for free advice in all matters affecting the geology or mineral industries of the State. A very considerable correspondence comes in, increasing rather than decreasing in amount, and asking specific and particular questions on points in local geology.

The volume of this correspondence has made it necessary to adopt a uniform method of dealing with these requests. Not all of them can be granted, but some can and should be answered. There is a certain element of justice in the people demanding such information, from the fact that the geological reports issued in former years were not so distributed as to make them accessible to the average man or community today. The cases commonly covered by correspondence may be classified as follows:

1st. Requests for information covered by previous publications.—This is furnished where the time required for copying the answer is not too large. Where the portion desired cannot be copied, the enquirer is told in what volume and page it occurs and advised how to proceed to get access to a copy of the report.

2nd. Requests for identification of minerals and fossils.—This is done, where possible. As a rule, the minerals and fossils are simple and familiar forms, which can be answered at once. In occasional cases, a critical knowledge is required and time for investigation is necessary. Each assistant is expected to co-operate with the State Geologist in answering inquiries concerning his field.

3rd. Requests from private individuals for analyses of minerals and ores, and tests to establish their commercial value.—Such requests are frequent. They cannot be granted, however, except in rare instances. Such work should be sent to a commercial chemical laboratory. The position has been taken that the Geological Survey is in no sense a chemical laboratory and testing station, to which the people may turn for free analytical work. Whatever work of this sort is done, is done on the initiative of the Survey and not at the solicitation of an interested party.

The greatest misapprehension in the public mind regarding the Survey is on this point. Requests for State aid in determining the value

of private mineral resources, ranging from an assay worth a dollar, up to drilling a test well costing several thousand dollars, represent extreme cases. At present there is no warrant for the Survey making private tests, even where the applicant is entirely willing to pay for the service. In many cases individuals would prefer the report of a State chemist or State geologist to that of any private expert, at equal cost, because of the prestige which such a report would carry. But it is a matter of doubt whether it will ever be the function of the Survey to enter into commercial work of this character; it certainly will not be unless explicit legal provisions for it are made.

4th. Requests from a number of persons representing a diversity of interests, who jointly ask the Survey to examine into and publicly report upon some matter of local public concern.—Such cases are not common. It is not always easy to determine whether such propositions are really actuated by public interest or not. Each case must be judged on its merits. The Survey will often be prevented from taking up such investigations by the lack of available funds, while otherwise the work would be attempted.

The reputed discovery of gold is one of the most prolific sources of such calls for State examination. It usually seems wise and proper to spend a small sum in preventing an unfounded rumor from gaining acceptance in the public mind, before it leads to large losses, and unnecessary excitement. The duty of dispelling illusions of this sort cannot be considered an agreeable part of the work of the Survey, but it is nevertheless of very direct benefit to the people of the State.

PUBLICATIONS OF THE SURVEY.

The Geological Survey of Ohio was organized for the first time in 1837. It was short-lived and issued only two publications, known as the First and Second Annual Reports, both dated 1838.

In 1869 the Survey was reorganized, and issued Volumes I to VI as well as a number of shorter reports. The third organization was effected in 1889 and published a First Annual Report for 1890 and Volume VII. All reports dated prior to Volume VII have long been out of print, but under recent action of the legislature the State Geologist is permitted to deal in these without financial gain or loss to the State.

The fourth organization of the Survey was effected in 1900. This has issued Bulletins 1-13, of which 9, 10 and 11 may be found in this volume.

PUBLICATIONS ON SALE AT THE OFFICE OF THE STATE GEOLOGIST.

All publications of earlier date than Volume VII (1894) are second hand. The pages are guaranteed complete, but maps snd sections, unless bound in the volumes, are generally wanting. Stamps are not accepted in payment for these publications.

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I. Report on the progress of the Geological Survey of Ohio in 1869 by J. S. Newberry.
II. A Report on the Straitsville Coal Field by Prof. E. B. Andrews.
III. A Report on the Geology of Montgomery County by Prof. Edward Orton.
This volume contains the first official geological map of the State.
Price $0.75

REPORT OF PROGRESS FOR 1870 (568 Pages.)

I. Sketch of the Structure of the Lower Coal Measures in Northeastern Ohio by J. S. Newberry.
II. Report of Labors in the Second Geological District during the year 1870 by E. B. Andrews.
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VOLUME II. (Geology, 701 pages; 1874.)

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Geology of the Hocking Valley Coal Field by M. C. Read. Supplemental Report on Perry County and Portions of Hocking and Athens counties by E. B. Andrews. Supplemental Report on the Hanging Rock District by Edward Orton.
Price $1.25

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Scale 4 miles to 1 inch, by J. S. Newberry. In 6 sections, unmounted.
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VOLUME IV. (Zoology and Botany, 1020 pages; 1882.)

Section I. Report on the Mammalia of Ohio by A. W. Brayton.
Section II. Report on the Birds of Ohio by J. M. Wheaton.
Section III. Report on the Reptiles and Amphibians of Ohio by W. H. Smith.
Section IV. Report on the Fishes of Ohio by David S. Jordan.
Price $1.25

VOLUME V. (Geology, 1124 pages; 1884.)

An Elaborate Discussion of the Coals of Ohio, principally by Dr. Edward Orton.
Price $2.50

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Nearly 600 pages of this volume treat of Petroleum and Natural Gas by Dr. Edward Orton, F. W. Minshall, F. J. Newell, Emerson McMillen and S. W. Robinson.

The volume contains chapters on the Pittsburg Coal in Belmont, Jefferson and Guernsey counties by C. N. Brown. The Pomeroy and Federal Creek Coal Field by Ellis Lovejoy. The Manufacture of Salt and Bromine by W. J. Root. Natural and Portland Cements by N. W. Lord. Gypsum and Land Plaster in Ohio by Edward Orton. The Production of Lime in Ohio by Edward Orton. The Drift Deposits of Ohio by Edward Orton.
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*The sale edition of Bulletin 3 is exhausted.

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By J. A. Bownocker, N. W. Lord and E. E. Somermeier.

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THE MIDDLE DEVONIAN OF OHIO.

By Clinton R. Stauffer.

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THE MANUFACTURE OF ROOFING TILES.

By Wolsey Garnet Worcester, with the Co-operation of Edward Orton, Jr.

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GEOLOGICAL MAP OF OHIO (IN POCKET.)

FOURTH SERIES, BULLETIN 9

COAL

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Part Two

CHEMICAL ANALYSES AND CALORIFIC TESTS OF THE CLARION, LOWER KITTANNING, MIDDLE KITTANNING AND UPPER FREEPORT COALS

GEOLOGY BY
J. A. BOWNOCKER

CHEMISTRY BY
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MAY, 1908

ASSISTANTS IN COAL MAPPING.

J. E. Hyde, A. M.
D. D. Condit.

ASSISTANTS IN COAL SAMPLING.

Prof. B. A. Eisenlohr.
Prof. E. E. Somermeier.
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MAPS.

MAP I. The Pittsburg Coal.

MAP II. The Pomeroy and Meigs Creek Coal.

CHAPTER I.

THE PITTSBURG COAL.[1]

Introduction. As is well known this is the most valuable coal seam in North America. It is found in the states of Pennsylvania, West Virginia, Ohio and Maryland, in all of which it is important. The area of workable coal in this seam is estimated by White at from 6,000 to 7,000 square miles. Orton estimated the area in Ohio alone at 1250 square miles, but this included the Pomeroy coal which is now known to lie above the Pittsburg seam.

Area. The area underlaid by this seam in Ohio forms two distinct fields, an Eastern and a Southern one. The Eastern Field is by far the most important, including nearly the whole of Belmont county, the southeastern part of Harrison, the southern part of Jefferson, the extreme eastern part of Guernsey, the northeastern part of Noble, the northern part of Monroe, and the northern part of Washington counties. The last four counties, however, are of very little importance, though one of them, Monroe, may prove to have valuable deposits of this fuel.

The Southern Field comprises the southwestern corner of Morgan county, the eastern part of Athens, the northern part of Meigs and the southeastern part of Gallia. The Southern Field may be divided into two parts, Morgan, Athens and Meigs counties forming one part and Gallia county the other. The structure of the seam in the two is similar. This field at present, is of minor importance, the fuel being shipped by rail or boat from less than a half dozen places.

Characteristic Structure of the Pittsburg Coal. Over most of the large territory in Ohio and other states, where the Pittsburg coal is found it has a characteristic structure. This is well illustrated below:

Roof coal.
Draw slate.
Breast coal.
Parting.
Bearing in coal.
Parting.
Brick coal.
Parting.
Bottom coal.

So persistent are these divisions that the coal may be identified by them over a wide territory. Occasionally, when the structure of the

[1] For method of sampling see Chapter IX.

seam is in general normal, the parting between the Brick and Bottom coals is wanting, but even in such cases there is commonly a bedding plane between these two members.

In Ohio, however, the seam shows marked variation in structure. Along the river in Jefferson and Belmont counties, where the seam is at its best, the structure is normal; that is it has the succession of coals and partings shown in the general section given above. Farther west, especially along the western border of Belmont county and near the western margin of the Eastern Field the structure of the seam is less constant. There the structure is occasionally normal, but more commonly variations are found. These points are well illustrated in the following sections.

The first section is from Neff Mine No. 2 near Bellaire. In this the structure of the coal may be considered normal, and is found in Pennsylvania, West Virginia and Maryland as well as in Ohio:

	Ft.	In.
Roof coal	1	0
Draw slate	0	10
Breast coal	2	3
Shale parting	0	¼
Bearing in coal	0	2
Shale parting	0	1
Brick coal	1	5
Pyrites parting	0	1½
Bottom coal	1	3

Below is another section, which, while differing from the above, may still be classed normal. This section was measured in Dillon Mine No. 2 at Dillonville, Jefferson county:

			Ft.	In.
Roof coal	Coal		0	2½
	Parting		0	1½
	Coal		1	6
	Parting		0	¾
	Coal		0	1½
Draw slate (soapstone)			1	0
Breast coal			2	6½
Parting			0	⅝
Bearing in coal	Coal	1⅝	0	4½
	Parting	⅝		
	Coal	2¼		
Parting			0	⅜
Brick and Bottom coals			2	8

Here the Brick and Bottom coals are not separated by a parting, while the Bearing in coal is thus divided. It will be noted that the structure of the Roof coal is more complex than that found in the last section,—and this structure is the more common one.

Compare these sections with the following one of the same seam found in the Media Mine about three miles southwest of Barnesville:

		Ft.	In.
Draw slate, unmeasured			
Black shale		0	1¾
Breast coal	Coal	0	¾
	Bone coal and pyrites	0	2
	Coal	0	11
Shale		0	1
Bearing in coal		0	5
Shale		0	½
Brick and Bottom coal		3	0

In this section the Breast coal is greatly contracted and subordinate in value while the other parts of the seam are thicker and of increased value.

At Temperanceville in the southwest corner of Belmont county the coal was found as follows:

	Ft.	In.
Shale, unmeasured		
Coal	0	10
Shale and pyrites	0	¾
Coal	3	0

This shows the seam divided into 3 parts, two of coal and one of shale with pyrites. The coal above the parting corresponds to the Breast coal, and is here of minor importance as a source of fuel. The parting itself represents the Bearing in coal with the partings above and below it. The coal below the parting comprises the Brick and Bottom parts of the seam.

The latter two sections are of great importance because they show the transition from the normal structure of the Pittsburg seam to that found farther southwest in Athens and Gallia counties.

Structure of the Pittsburg Coal in Athens and Gallia Counties. Here a marked change occurs. The well-known structure of the seam is wanting and instead a three-fold division is found. This consists of an "Upper bench" and a "Lower bench" of coal separated by a layer of clay or shale. This structure is almost as persistent in Ohio as the well known one in the eastern part of Belmont and Jefferson counties. Usually too, the Lower bench is the more important and in places is the only one mined. It is evident that the structure of the seam is here comparable to that found at Temperanceville, Belmont county. Interesting to note is the fact that at one point in Gallia county the structure of the seam is quite similar to that found farther east. Whether this is of significance or is a lucky accident cannot be stated. These points are illustrated in the following sections:

Section of the Pittsburg coal at Sharpsburg, Athens county:

		Ft.	In.
Shale, unmeasured			
Upper bench	Coal	4	0
	Bone coal	0	2
	Coal	0	4
Clay parting		1	0
Lower bench	Coal	2	10
	Pyrites parting	0	½
	Coal	0	8

Below is a section of the same seam at Bladen, Gallia county on the bank of the Ohio River:

	Ft.	In.
Shale	2	0
Upper bench, Coal	0	4½
Clay	1	0
Lower bench, Coal	2	9

Usually, however, the structure is more complex than shown in the last section. Occasionally, too, the seam shows the ear marks of the structure in Belmont county. The following section measured in Kern's bank near Angel P. O. in Gallia county, illustrates both points:

		Ft.	In.
Roof coal, reported	Coal	1	8
	Soapstone		
	Coal	2	0
Draw slate		2	5
Breast coal or Upper bench	Dirty coal	0	1
	Coal	2	5
	Streak of dirty coal		
	Coal	0	6
	Parting	0	1¾
	Coal	0	11½
Parting	Parting, pyrites	0	1⅝
	Bearing in coal	0	1
	Parting, pyrites	0	¾
Lower bench	Brick coal	0	8½
	Parting	0	¼
	Bottom coal	0	10

Summary. From what has been said it is apparent that the structure of the Pittsburg coal in Ohio presents two distinct phases: (1) That in the eastern counties the structure is usually normal, that is, similar to that found in the great fields east of the Ohio River; (2) that farther southwest in Ohio the structure of the seam is markedly different but persistent in that territory; (3) that between these two phases are intermediate forms which may be regarded transitional.

THE PITTSBURG COAL IN BELMONT COUNTY.

Introduction. This county not only contains the largest quantity of Pittsburg coal of any county in Ohio, but it also contains more coal than any other county in the state.

Every township in the county except Flushing and Kirkwood contains a large area of this seam, and eight townships are almost completely underlain with it. The seam is everywhere of workable thickness and of good quality and hence the county contains a very large quantity of fuel. It is the last of the great coal fields in our state to be developed on a large scale, and it promises to be the most lasting in supply.

Early History. Outcropping as the coal does at so many places, its presence must have been known to residents of the county from the time of its settlement. Probably the fuel began to be used for domestic purposes as early as 1825. Messrs. R. H. O'Neil and Evans Lake are said to have been the pioneer miners and about 1835 the fuel was shipped by river from a mine located on the south bank of McMahon's Creek at Bellaire. At approximately the same time other mines were opened at the north end of Bellaire and West Wheeling.

Between 1835-40 Jacob Heatherington and John Fink opened a mine just south of Bellaire on land now within the corporation limits, and a few years later a mine was opened at Wegee, six miles farther south.

About 1845 the river shipment of coal became active, the fuel being sent as far south as New Orleans. At first the coal was loaded on flats and allowed to drift, but after 1850 the fuel was shipped principally in barges. Much coal was used on the boats for steam purposes and Bellaire became a regular stopping place for loading.

The first railroad mine in the county is said to have been opened in 1858, the locality being one mile west of Bellaire. This mine supplied coal for locomotives and also for shipment. About 10 years later another railroad mine was opened, the location being at Franklin Station 8 miles west of Bellaire. Since that year, other mines have been opened from time to time, but it was not until about the year 1900 that the present boom began.[1]

Belmont county is now the second largest producer of coal in Ohio and probably this lead will be increased from year to year until the county becomes by far the greatest producer in the state.[2]

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[1] Historical data by Hon. J. F. Anderson of Bellaire.

[2] Advance reports for 1907 indicate that Belmont county is by far the largest producer in the state.

Statistics. The following figures show the output of the county for several years past:[1]

Year.	Output.	Rank of county in coal production.	Total production of state. Short tons.
1896	919,076	7	12,875,202
1897	827,420	6	12,196,942
1898	1,036,102	6	14,516,867
1899	1,242,383	6	16,500,270
1900	1,345,284	6	18,988,150
1901	1,506,858	6	20,943,807
1902	1,997,956	6	23,519,894
1903	2,725,849	4	24,838,103
1904	3,172,350	2	24,400,220
1905	3,957,980	1	25,552,950
1906	4,266,865	2	27,731,640

In considering the future of Belmont county as a coal producer, it should be remembered that at present the southern two-fifths of her territory do not produce a ton from this seam. This large area, however, is underlain with coal, and in time will be the seat of extensive mining operations. All that is now needed in that territory is transportation, and the valley of Captina Creek furnishes an easy line for railroad construction.

Pease Township. Nearly the whole of this township is underlain with the Pittsburg coal. The Ohio River which forms the eastern boundary of the township has cut far below the seam, and several tributaries of this river have also cut through it. Especially is this true of Wheeling Creek which crosses the township along its southern edge, and a branch of Short Creek in the northwestern corner.

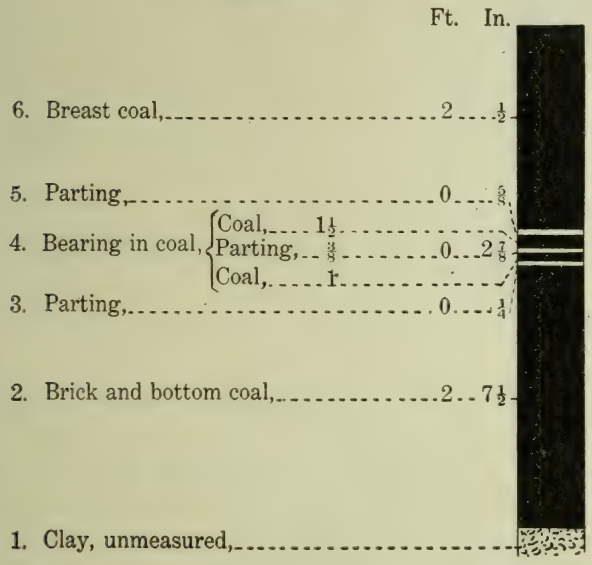
The coal has long been mined along the river front for local use. The fuel is hauled directly from these hills to the iron and steel mills in the valley, thus reducing to a minimum the cost of fuel.

Section 1 shows the coal in the mine which supplies the Aetna-Standard mill with fuel, the location being at the north end of Bridgeport. Occasional streaks of pyrites are found in the lower part of the seam, and one thin smut band was noted. Much the same may be said of the Breast coal. The Bearing in coal is not rejected. The Draw slate overlying the coal is reported to vary from a foot or more in thickness to almost nothing.

[1] Statistics taken from United States Geol. Survey Reports.

The entire output of this mine is used by the mill. It is said that the mine was opened in 1873 and that 268 acres have been worked out. The supply in the hills, however, is adequate at the present rate of consumption to last an indefinite period.

SECTION 1



Chemical analysis and calorific value of Section 1:

Ultimate.		*Proximate.*	
Carbon	71.45	Moisture	3.39(a)
Hydrogen	5.21	Volatile Matter	36.84
Oxygen	11.27	Fixed carbon	51.91
Nitrogen	1.24	Ash	7.86
Sulphur	2.97		
Ash	7.86		
	100.00		100.00

Calorific value ..... 7,217 calories.

(a) Moisture in the air-dried sample about 3%.

The sample included parts 2 and 6 only of the section, though all parts, except 1, are mined and used. The sample was 6 inches wide and 2 inches thick and is regarded excellent.

In a ventilating shaft of the old Wheeling Creek Mine in section 3, Professor Brown measured the following section:[1]

	Ft.	In.
Limestone	12	0
Clay	4	0
Pomeroy or 8a coal	0	6

[1] Vol. VI, p. 606.

		Ft.	In.
Clay		1	0
Clay and shale		2	0
Limestone, bedded		16	0
Limestone, nodular		3	0
Clay		2	8
Black shale		0	2½
Roof coal (Pittsburg)		1	0
Clay		0	10
Pittsburg coal	Coal	2	6
	Parting	0	1
	Coal	0	4
	Parting	0	½
	Coal	0	8
	Parting (thin)		
	Coal	0	8
	Parting (thin)		
	Coal	1	3
Limestone		0	4
Clay, unmeasured.			

The coal is quite uniform in thickness and structure throughout the township. Occasionally the Bearing in coal which usually consists of a thin layer of coal with a shale or clay parting above and below, is replaced by a single band of shale. Sometimes the Brick and Bottom coals are separated by a parting of shale, but at other places these coals are directly in contact.

Along Wheeling Creek the coal was formerly coked, but the product contained too much sulphur to enable it to compete with that made at Connellsville.

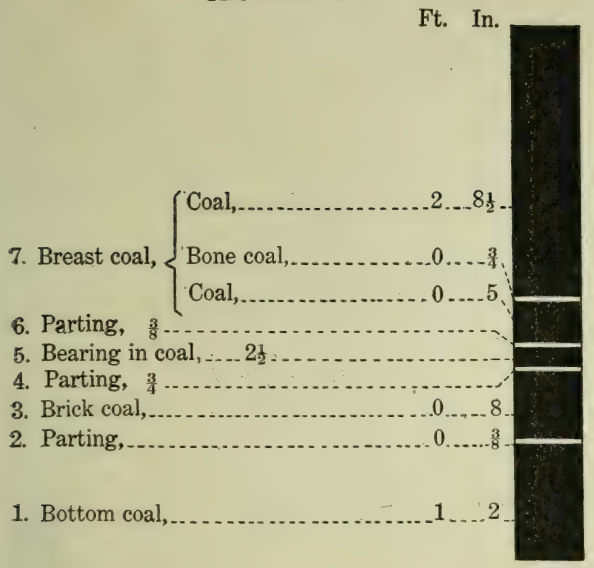
The Roof coal, as usual, varies in thickness. In places it measures only one foot and elsewhere from two to three feet, but the latter is uncommon. Usually the Roof coal lies directly above the Draw slate. It is not mined.

At Bridgeport the coal is 76 feet above the C. & P. R. R. tracks. It rises rapidly to the north, being 121 feet above the tracks at Martin's Ferry and still higher farther north in Jefferson county. In the southern part of the township the coal dips to the east at the rate of about 25 feet per mile.

Colerain Township. This township lies directly west of Pease and contains a large area of coal. Wheeling Creek crosses the southeastern part of the township in a deep valley along which the coal is everywhere above drainage. The coal is extensively mined.

Section 2 shows the coal in a mine of the Y. & O. Coal Company at Barton. The capacity of this mine was given at 1,000 tons per day.

SECTION 2



Chemical composition and calorific value of Section 2:

Ultimate.		*Proximate.*	
Carbon	70.41	Moisture	3.79(a)
Hydrogen	5.14	Volatile Matter	36.37
Oxygen	10.20	Fixed carbon	50.84
Nitrogen	1.09	Ash	9.00
Sulphur	4.16		
Ash	9.00		
	100.00		100.00

Calorific value ..... 7,145 calories.

(a) Moisture in the air-dried sample about 3%.

This sample included parts 1, 2, 3, 6 and 7 of Section 2.

At Maynard in section 1, near the western border of the township, Professor Brown found the coal as follows:

	Ft.	In.
Roof coal, about	1	6
Draw slate (soapstone)	0	10
Breast coal { Bone coal	0	3
Breast coal { Coal	1	6
Shale parting		
Bearing in coal	0	7
Shale parting		
Brick coal	1	6
Parting	0	
Bottom coal	1	0

Sections similar to the two just given can be duplicated in large number. The Roof coal ranges ordinarily from 12 to 18 inches in thickness and usually lies directly above the Draw slate. It is not mined. The structure of the main seam is characteristic, and can be duplicated in Pennsylvania, West Virginia and Maryland.

Flushing Township. This township forming the northwest corner of the county is completely underlain with coal in its eastern part. The central part has the coal in the high ridge between two branches of Stillwater while the area of coal in the western part is small and confined to the tops of the highest hills.

Section 2a shows the coal in the mine of the Kennon Coal & Mining Co. near Flushing.

SECTION 2 a

	Ft.	In.
7. Draw slate,	0	10
6. Bone coal, rejected,	0	2½
5. Breast coal,	1	7
4. Parting,	0	¼
3. Bearing in coal,	0	2
2. Parting,	0	¼
1. Brick and bottom coal,	2	5

A film of pyrites was observed 23 inches above the bottom but is not continuous. The Roof coal is reported to average 10 inches. The mine was opened about 1902.

Chemical analysis and calorific value of sample 2a:

Ultimate.		*Proximate.*	
Carbon	68.75	Moisture	4.23(a)
Hydrogen	5.14	Volatile Matter	36.34
Oxygen	11.64	Fixed carbon	50.22
Nitrogen	1.09	Ash	9.21
Sulphur	4.17		
Ash	9.21		
	100.00		100.00

Calorific value ..... 7,003 calories.

(a) Moisture in the air-dried sample about 3%.

All was included in the sample except parts 6 and 7. Part 6 is rejected in the mine as well as in the sample. The sample was about 6 inches wide and one inch thick.

In the southwestern quarter of section 26 Professor Brown made the following measurement of the seam:

	Ft.	In.
Draw slate	0	10
Breast coal	1	10
Bearing in coal (slaty coal)	0	3
Brick coal	1	10
Shale or clay parting	0	1¼
Bottom coal	1	0
Clay	1	2
Limestone, unmeasured.		

This seam shows some changes from that found farther east in the county. Thus the Bearing in coal which usually consists of coal with a subordinate quantity of shale or clay is replaced with a band of shaly coal. Further the parting between the lower two divisions of the seam is abnormally large.

Formerly a part of the slack from this mine was used for making coke.

In the northwest quarter of section 8, near the middle of the township, Professor Brown found the coal as follows:[1]

	Ft.	In.
Massive sandstone, unmeasured.		
Breast coal	0	10
Clay or shale parting	0	½
Bearing in coal	0	3
Shale parting	0	½
Brick and Bottom coal	2	5
Clay	2	6
Limestone, unmeasured.		

This section, as Professor Brown remarks, had the Roof coal, Draw slate and part of the Breast coal cut out by the sandstone ledge. "The eastern edge of this cut out is a short distance west of Rock Hill (section 32). The sandstone is well shown in the top of the ridge extending northwest from Rock Hill and seems to thicken to the west, reaching a thickness of from 20 to 25 feet."

The Ames limestone is well shown in the valley of Big Stillwater and tributaries. It ranges from 2 to 2½ feet in thickness and is highly fossiliferous.

Pultney Township. This township fronts on the Ohio River. Everywhere along this front the coal is above low water level and hence has been removed in the river valley. McMahon's Creek, which crosses the township from west to east, everywhere cuts through the coal, and the same is true of a tributary from the northwest. With these exceptions the township is underlain with the seam, save the very small areas from which the coal has already been mined.

The following interesting section measured by Mr. J. E. Hyde on the north side of McMahon's Creek about one mile west of Bellaire, shows the strata above the Pittsburg coal:

[1] Vol. VI., p. 611.

	Ft.	In.
Gray calcareous shales	14	0
Gray limestone, fine grained	1	0
Gray shales	3	0
Limestone and limy shales full of minute crustacean remains	1	6
Gray argillaceous shales	3	3
Meigs Creek Coal	5	0
Dark gray sandy shales	0	7
Sandy micaceous clay	0	7
Sandy micaceous shale	0	3
Sandstone, varies much	7	0
Parting of black shale	0	
Clay shale	0	6
Sandstone, quarried	16	6
Coal	0	4
Fire Clay	0	5
Coal	1	3
Limestone with layers of shale near top	6	10
Calcareous shales	2	3
Light gray limestone	6	6
Gray shale, argillaceous	1	10
Limestone	2	9
Shales	2	6
Shales and limestone, the latter thin-bedded	2	4
Clay shale	1	10
Limestone with shaly layers	4	0
Gray argillaceous shale	3	9
Pomeroy or Redstone coal	1	3
Gray argillaceous shale	0	9
Hard gray amorphous limestone with numerous minute fossils	2	0
Gray shale	0	4
Limestone, hard gray amorphous, with numerous minute fossils	1	0
Gray calcareous shale, with some minute fossils	2	3
Limestone, hard gray, amorphous with some fossils	2	0
Shales, hard with some lime and fossils	2	6
Unseen	12	6

Top of Pittsburg coal.

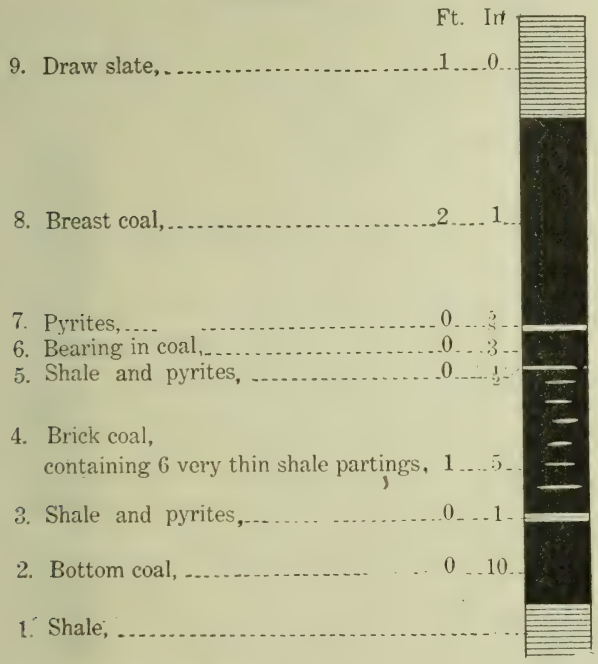
This section shows the intervals between the Pittsburg and Pomeroy or Redstone coals to be 23 feet and between the Pittsburg and Meigs Creek coals 86 feet. These intervals are fairly regular and may be traced southwest to Lawrence county, though ordinarily one of the three coal seams is very thin or wanting. The limestone recorded in this section between the Pittsburg and Pomeroy coal is persistent, having been found as far southwest as Pomeroy. In that part of the state, however, the limestone is much thinner than that shown in the section.

Section 3 shows the Pittsburg coal as found in the mine of the Empire Coal Mining Company one mile south of Bellaire.

No measurement of the Roof coal was made but it is reported from

6 to 18 inches thick and separated from the Breast coal by from one to two and one-half feet of shale. Occasionally, however, the Roof coal is said to rest directly on the Breast coal. It is not mined.

SECTION 3



When this mine was visited (July, 1907) its capacity was 1,000 tons per day but this was soon to be doubled. The coal is shipped by river to various places and by rail to Indiana and northwest to the Great Lakes. Considerable of the output is used by the Pennsylvania Railroad and some finds a local market in Bellaire.

Chemical analysis and calorific value of sample 3:

Ultimate.		*Proximate.*	
Carbon	72.06	Moisture	3.51(a)
Hydrogen	5.45	Volatile Matter	38.65
Oxygen	10.70	Fixed carbon	50.98
Nitrogen	1.17	Ash	6.86
Sulphur	3.76		
Ash	6.86		
	100.00		100.00

Calorific value ..... 7,325 calories.

(a) Moisture in the air-dried sample about 3%.

In the sample all of the section was included except parts 1, 3, 5, 7 and 9. The sample was 6 inches wide and 3 inches thick. The face of the coal from which the sample was cut was rather loose owing

to shooting. This made it rather difficult to keep the section of uniform width. Nevertheless, the sample is believed to be fair.

Section 4 was measured in Neff Mine No. 2 in section 13, on the western side of the township.

SECTION 4

	Ft.	In.
9. Draw slate,	0	10
8. Bone coal, marketed,	0	1 ½
7. Breast coal, contains 4 pyrites streaks,	2	1 ½
6. Shale parting,	0	¼
5. Coal, including a pyrites band near middle,	0	2
4. Shale parting,	0	1
3. Brick coal, including 2 thin pyrites lenses,	1	5
2. Pyrites parting,	0	1 ½
1. Bottom coal,	1	3

The Roof coal was reported to vary in thickness from 2 feet to a few inches, and was not mined. It was said to contain much pyrites.

This mine has been in operation about three years, and when visited was producing 350 tons per day.

Chemical composition and calorific value of Section 4:

Ultimate.		*Proximate.*	
Carbon	70.57	Moisture	3.80(a)
Hydrogen	5.23	Volatile Matter	37.18
Fixed carbon	9.78	Fixed carbon	50.07
Nitrogen	1.20	Ash	8.95
Sulphur	4 27		
Ash	8.95		
	100.00		100.00

Calorific value ..... 7,103 calories.

(a) Moisture in the air-dried sample about 3%.

This sample included all parts of the section except 2, 4 and 9. These were rejected by the miner also.

The sample was cut in the side of a room which had been exposed

about two weeks, but before sampling 2 or 3 inches of the surface of the coal were first removed. The cross section of the sample measured 6x3½ inches.

Richland Township. The land of this township is high, forming a watershed between Wheeling and McMahon's Creeks. In the northern part of the township the seam is exposed along Wheeling Creek and to a small extent along its tributaries. In the southeastern part of the township the coal is shown in the valley of McMahon's Creek, the seam disappearing beneath the bed of this stream a short distance east of Glencoe. The coal is mined by shafting near this village and a section will be found in the discussion of Smith township. When found the coal is normal in thickness and structure. Manifestly this township contains a very large quantity of the Pittsburg coal.

Union Township. This township is underlain with the Pittsburg coal except along its western edge where the headwaters of Stillwater Creek have in part removed it.

The coal is mined for shipment by the Wheeling Valley Coal Company at Lafferty, in the northeastern part of the township where Section 5 was made.

SECTION 5

	Ft.	In.
10. Draw slate soapstone,	1	0
9. Impure coal, rejected,	0	2
8. Breast coal,	1	9
7. Parting,	0	¾
6. Bearing in coal,	0	2
5. Parting,	0	¼
4. Brick coal,	1	8½
3. Parting,	0	⅜
2. Bottom coal,	1	2
1. Clay, unmeasured,		

This mine was opened about a year ago, (1906.) It has a steel tipple and is modern in all respects. The capacity of the mine is about 2,800 tons per day.

Chemical analysis and calorific value of Section 5:

Ultimate.		*Proximate.*	
Carbon	68.24	Moisture	4.46(a)
Hydrogen	4.85	Volatile Matter	36.00
Oxygen	10.60	Fixed carbon	48.78
Nitrogen	1.10	Ash	10.76
Sulphur	4.45		
Ash	10.76		
	100.00		100.00

Calorific value ..... 6,903 calories.

(a) Moisture in the air-dried sample about 3%.

The sample included the entire section except parts 1, 5, 6, 7, 9 and 10.

Along the western side of the township the seam has been mined by the farmers at a number of places. Professor Brown reports the coal from 3 feet 9 inches to 4 feet thick with a thin parting near the middle, in section 36 in the northwestern corner of the township. This structure is similar to that found in the same seam to the southwest in Athens and Gallia counties.

Kirkwood Township. This lies west of Union township and contains the coal in the higher hills and ridges only. The coal is not mined for railroad shipment, but supplies a local demand among the farmers.

Section 6 was measured in the bank of F. W. McCartney, one-half mile west of Hendrysburg.

SECTION 6

	Ft.	In.
6. Roof coal, reported,	1	0
5. Draw slate, reported,	0	6
4. Impure coal,	0	3
3. Breast coal, with numerous pyrites and shale lenses,	1	2 ½
2. Shale, and pyrites,	0	1
1. Brick and bottom coal,	2	11

PLATE I. Exterior Works of the Wheeling Valley Coal Co. at Lafferty, Belmont Co. Steel Tipple, Endless Chain Hoist, Self-dump, Electric Lighting and Power.

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Here also the coal is divided into two benches by a parting. The Bearing in coal has disappeared, its place being taken by a parting of shale and pyrites, and the Brick and Bottom coals form a single bed. The duplicate of this structure can be found in Athens and Gallia counties. The Roof coal is not mined but is reported the best in the seam.

Chemical composition and calorific value of Section 6:

Ultimate.		*Proximate.*	
Carbon	67.41	Moisture	3.75(a)
Hydrogen	5.09	Volatile Matter	37.99
Oxygen	10.79	Fixed carbon	47.42
Nitrogen	1.11	Ash	10.84
Sulphur	4.76		
Ash	10.84		
	100.00		100.00

Calorific value ..... 6,865 calories.

(a) Moisture in the air-dried sample about 3%.

Parts 1 and 3 were included in the sample, the remaining parts of the section being rejected by both miner and sampler. The sample was 5 inches wide and 2½ inches thick.

In the Lightell mine, section 29, in the northwest corner of the township, Professor Brown found the coal as follows:

	Ft.	In.
Massive sandstone	22	0
Black slate	0	1
Slaty coal, used	0	4
Breast coal	1	0
Shale and pyrites	0	1
Bearing in coal	0	3
Shale	0	¼
Brick coal	1	6
Shale	0	1
Bottom coal	1	2½
Clay	0	5

Limestone, unmeasured.

This section lies nearer the western margin of the field than the preceding section and yet shows the normal structure of the seam. The structure of the seam is less steady along its western margin in this part of the state, and sometimes the usual divisions are wanting.

Wheeling Township. The Pittsburg or No. 8 coal underlies the whole of this township except along Wheeling Creek and tributaries where the coal has been removed by erosion. Near the middle of the township the seam disappears beneath the bed of Wheeling Creek.

Section 6a represents the coal in the mine of the Columbian Coal Company at Fairport.

The coal contains about the usual quantity of pyrites though no

SECTION 6 a

		Ft.	In.
7. Draw slate, soapstone,			
6. Breast coal,	Coal,	1	½
	Smut rock,	0	⅜
	Coal,	0	8½
5. Smut rock,		0	⅛
4. Bearing in coal,		0	5¼
3. Smut rock,		0	⅛
2. Brick and bottom coal,	Coal,	0	1½
	Parting,	0	½
	Coal,	2	2
	Parting,	0	¼
	Coal,	0	6½
1. Clay, unmeasured,			

regular bands of it exist. The mine has a daily capacity reported at 1100 tons.

Chemical analysis and calorific value of Section 6a:

Ultimate.		*Proximate.*	
Carbon	68.17	Moisture	4.25(a)
Hydrogen	5.19	Volatile Matter	33.53
Oxygen	11.25	Fixed carbon	51.87
Nitrogen	1.09	Ash	10.35
Sulphur	3.95		
Ash	10.35		
	100.00		100.00

Calorific value .....6903 calories(b).

(a) Moisture in the air-dried sample about 3%.

(b) The ultimate analysis and calorific value here given was not obtained until several weeks after the preparation of the fine sample and laboratory experiments indicate that the sample had increased in weight by oxidation about 1½%. A calorific value about 100 calories higher than that given appears to represent more nearly the fresh sample.

In this sample parts 2 and 6 only of the section were included.

Professor Brown reports that the coal is normal along the eastern border of the township, ranging from five to five and one-half feet in thickness and having the customary partings.

In the northeastern quarter of section 26 Professor Brown found the coal as follows:[1]

[1] Vol. VI., p. 610.

		Ft.	In.
Roof coal, unmeasured.			
Draw slate		1	0
Breast coal	Coal	0	6
	Shale parting	0	1
	Coal	1	0
Shale			
Bearing in coal		0	6
Shale.			
Brick and Bottom coal		2	11
Clay		1	0
Limestone, unmeasured.			

Here the Breast coal is divided into two parts by a thin band of shale, while the Brick and Bottom coals are without the shale band that is so commonly found between them.

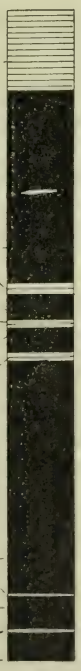
The Roof coal is nowhere reported prominent in the township. Probably its average thickness does not exceed one foot.

Smith Township. This township is competely underlain with the Pittsburg coal, the seam rising nowhere to the surface. The coal is mined in the northeast corner of the township near the village Glencoe, and a shaft has been sunk near Warnock station.

Section 7 was measured in Delora Mine, No. 1, about a quarter of a mile west of Glencoe. The mine belongs to the Highland Coal Company of Wheeling.

SECTION 7

		Ft.	In.
6. Draw slate,		0	10
5. Breast coal,	Coal with one pyrites band,	1	11
	Pyrites,	0	1¼
	Coal,	0	3
4. Pyrites parting,		0	1
3. Bearing in coal,		0	3
2. Pyrites parting,		0	1
1. Brick and bottom coal,	Coal,	2	4
	Pyrites,	0	⅛
	Coal,	0	4
	Pyrites,	0	⅛
	Coal,	0	3½



This mine is located in the valley of McMahon's Creek, the coal lying 55 feet below the bed of that stream.

The bearing in is made in the middle member of the Brick and Bottom coals. This part was included in the sample. The lower 3½ inches and the pyrites just above are left in the mine and were not included in the sample.

The Roof coal is reported one foot thick and lies directly above the Draw slate. Above the Roof coal is a heavy bed of soapstone. The Draw slate falls if not supported and the weight of the soapstone above the Roof coal makes keeping the entries clear rather difficult.

The seam is quite uniform in thickness. About 4 inches are left in the floor, below the cut made by the machines. The pyrites layers are fairly steady and the thicker ones are rejected.

When visited the mine was producing 1,000 tons per day, but had produced as high as 1,200 tons. This township has thirty-six square miles of the Pittsburg coal, and thus far the area has been little more than touched.

Chemical analysis and calorific value of Section 7:

Ultimate.		*Proximate.*	
Carbon	71.49	Moisture	3.21(a)
Hydrogen	5.14	Volatile Matter	36.82
Oxygen	10.77	Fixed carbon	52.71
Nitrogen	1.06	Ash	7 26
Sulphur	4.28		
Ash	7.26		
	100.00		100.00

Calorific value .....7,297 calories.

(a) Moisture in the air-dried sample about 3%.

Since the lower two members of part 1 were left in the mine they were not included in the sample. Parts 2, 3 and 4, which were also rejected by the miners were omitted in sampling. The sample measured 5 by 3 inches and is considered very fair.

Mead Township. This township lies south of Pultney and fronts on the Ohio River. The coal has long been mined along this stream. At present the principal mine is in the southeast corner of the township, about a quarter of a mile above the mouth of Pipe Creek. The mine is owned by the Johnson Brothers of Bellaire, and the structure of the coal is shown in Section 8.

The upper part of the Breast coal contains a number of pyrites lenses, but these are less numerous below. The Breast coal is considered the best part of the seam.

The Brick and Bottom coal contained at the place of sampling 7 smut streaks, the thickest measuring one-fourth of an inch; also 3 bands of impure hard coal ranging from one-half to one inch in thickness.

SECTION 8

	Ft.	In.
6. Draw slate,	1	4
5. Breast coal,	2	3
4. Shale parting,	0	½
3. Bearing in coal,	0	4½
2. Shale parting,	0	½
1. Brick and bottom coal,	3	2

The Draw slate is said to contract occasionally to one inch. Above it is found a thin band of coal measuring from one to two inches, and above this two feet of shales succeeded in turn by two feet of Roof coal.

The coal lies at the level of the river bed and is reached in the mine by an incline. Mining is done by compressed air and haulage by electricity. The mine was opened about 1902 and ships from 100 to 350 tons daily.

Chemical analysis and calorific value of Section 8:

Ultimate.		*Proximate.*	
Carbon	72.95	Moisture	2.91(a)
Hydrogen	5.11	Volatile Matter	37.94
Oxygen	8.59	Fixed carbon	51.15
Nitrogen	1.04	Ash	8.00
Sulphur	4.31		
Ash	8.00		
	100.00		100.00

Calorific value ..... 7,340 calories.

(a) Moisture in the air-dried sample about 3%.

A lense of pyrites found in part 5 of the section was rejected in the

sample. Parts 2, 4 and 6 were also rejected. The sample measured 2 by 4 inches and was cut from a face only two days old.

Three diamond drill tests have been made in this township by Hon. Samuel L. Mooney, of Woodsfield, who has placed the records at the disposal of the survey. In the southeast quarter of section 2 the coal measured 5 feet 1 inch and in the northeast quarter of section 8, 5 feet 5 inches. In the former case the Roof coal measured only 3 inches, but in the latter it was found thicker but with several partings of shale or clay.

Below is a complete record of the well drilled at Vallonia in the northwest quarter of section 14:

	Ft.	In.
Surface	6	00
Limestone	0	06
Limestone and shale, mixed	0	09
Limy shale	0	06
Soft gray shale	1	00
Sandy shale	1	00
Sandstone, gray	6	06
Gray shale	5	03
Limestone	0	06
Gray shale	0	03
Limestone	1	03
Soft green shale	1	06
Fire clay	0	06
Dark shale	0	03
Sandstone, gray	10	00
Gray shale	1	06
Dark shale	0	03
Limestone	0	06
Hard dark limy shale	1	03
Limestone	1	04
Limy shale	0	03
Hard shale with lime nodules	1	04
Limestone	0	09
Limy shale	0	04
Limestone and shale, mixed	0	06
Limy shale	1	00
Limestone	0	06
Gray shale	0	06
Limestone	0	08
Gray shale	1	06
Dark limy shale	0	08
Green limy shale	0	08
Sandy shale	1	00
Limy shale	0	06
Limestone	1	03
Limy shale, hard	1	06
Limestone	0	04
Cement rock	1	09
Hard limy shale and limestone	1	06
Dark shale and limestone, mixed	0	08
Gray shale	0	06

	Ft.	In.
Limestone	2	03
Gray shale	1	03
Cement rock	3	06
Hard dark, limy shale	3	09
Green shale	3	00
Red shale	0	03
Hard green shale	1	00
Limestone	0	08
Hard gray shale	0	04
Hard limy shale	0	09
Cement rock	5	03
Hard green shale	0	09
Hard gray limy shale	0	06
Limestone and shale, mixed	1	00
Gray sandstone	2	02
Gray and sandy shale	1	06
Cement rock	4	00
Hard dark limy shale	1	09
Limestone and cement rock, mixed	3	00
Hard dark limy shale	0	09
Limestone and cement rock, mixed	1	09
Hard limy shale	2	00
Limestone	0	08
Hard dark limy shale	1	00
Cement rock	4	00
Hard dark limy shale	0	03
Limestone	2	09
Hard gray shale	0	05
Limestone mixed with shale	0	06
Limestone and cement rock, mixed	1	04
Hard green limy shale	0	05
Limestone	0	08
Green limy shale	1	00
Hard dark gray slate	1	04
Cement rock	2	08
Limestone	0	03
Hard limy shale	0	08
Limestone, gritty	1	06
Hard limy shale	0	06
Cement rock	2	00
Hard limy shale	0	06
Limy shale with little limestone	0	08
Cement rock	2	00
Gray slate	1	00
Between limestone and cement rock	3	06
Hard dark limy shale	1	06
Green limy shale	0	07
Hard dark gray shale	2	03
Hard dark limy shale	1	02
Limestone and shale, mixed	0	06
Limestone	0	09
Limy shale, hard	0	07
Limestone	0	05

	Ft.	In.
Hard limy shale	3	06
Limestone and shale, mixed	0	05
Fire clay	2	08
Slate, dark	0	02
Coal, Meigs Creek	3	09
Sandy fire clay	0	08
Hard limy shale	1	00
Limestone	0	06
Soft gray shale with lime nodules	2	07
Sandy shale	8	00
Gray slate	7	03
Brown slate	1	00
Coal	0	05
Band	0	03
Coal	0	09
Dark limy shale	0	06
Limestone	2	03
Cement rock	1	03
Hard limy shale	0	03
Limestone	3	06
Cement rock	4	03
Hard dark gray shale	0	03
Limestone	2	00
Gray shale	1	00
Limestone	4	00
Hard limy shale	0	04
Limestone	1	04
Hard shale and limestone, mixed	0	10
Hard gray shale	1	00
Limestone and shale, mixed	0	06
Limestone	1	10
Hard limy shale	0	09
Green shale with lime nodules	1	00
Fire clay	1	06
Black slate	0	03
Green and black slate, mixed	0	09
Soft clay shale	2	09
Gray shale	1	06
Sandy shale	1	06
Black shale	0	03
Hard dark limy shale	1	06
Blue limestone	2	00
Limestone, gray	2	06
Hard dark limy shale	0	06
Blue limy shale, hard	1	03
Limestone and shale, mixed	1	03
Hard limy shale	3	00
Limestone and shale, mixed	0	03
Hard limy shale	2	00
Limestone and shale, mixed	2	00
Hard limy shale	0	09
Fire clay	1	09
Hard limy shale	0	06

	Ft.	In.
Fire clay and dark shale, mixed	0	11
Black slate	0	04
Roof coal	1	00
Band	0	03
Roof coal	0	05
Band	1	11
Coal, Pittsburg	5	00
Dark fire clay	0	04
Hard limy shale	1	07

Interesting to note none of these tests shows the Pomeroy or Redstone coal. The Meigs Creek coal was found thin and unimportant in the first well, but in the second one it measured 4 feet 1 inch with a half inch parting of pyrites. In the third well, as shown above, this seam measured 3 feet 9 inches.

York Township. This township forms the southeastern corner of the county. It fronts on the Ohio River and the coal is said to lie in the bed of this stream. Interesting to report the seam rises above drainage along Captina Creek in sections 21 and 27, near the middle of the township where it has been mined to a small extent. This plainly indicates the presence of an arch or anticline. Elsewhere in the township the coal is under cover.

On the Dorsey farm, southwest quarter of section 14, Professor Brown made the following measurement of the coal:

	Ft.	In.
Roof coal, average	1	8
Draw slate, average	1	2
Breast coal	2	1
Shale and pyrites	0	1
Bearing in coal	0	6
Shale	0	1
Brick coal	1	7
Pyrites band	0	1
Bottom coal	0	10

Coal, thin band, not measured.
Clay, unmeasured.

The coal is reached by a shaft 25 feet deep, and the fuel is lifted by horse power.

Washington Township. The coal in this township is everywhere below drainage, and so far as can be judged the township is everywhere underlain with the seam.

The coal has long been mined near Armstrong's Mills in the northeastern part of the township. Section 9 was measured in the mine of the Captina Coal Company in the northwest quarter of section 10.

The Roof coal is reported to vary from 10 to 15 inches in thickness and lies directly above the Draw slate. It is unmined but makes a good roof.

SECTION 9

	Ft.	In.
9. Draw slate,	0	10
8. Bone coal, rejected,	0	3
7. Breast coal, with 3 thin partings,	2	8
6. Shale,	0	1
5. Bearing in coal,	0	8½
4. Shale,	0	⅜
3. Brick coal, containing several smut bands,	1	8½
2. Shale,	0	½
1. Bottom coal, with occasional pyrites lenses,	1	1

When visited in July, 1907, the mine was shipping about 80 tons of coal daily to points along the Ohio River and Western Railroad. The coal is regular and quite hard except a part about 10 inches above the base where the undercutting is done. Eighteen inches of the upper part of the Breast coal is very hard and blocks of considerable size are frequently loaded.

Chemical analysis and calorific vaue of Section 9:

Ultimate.		*Proximate.*	
Carbon	69.76	Moisture	2.79(a)
Hydrogen	5.25	Volatile Matter	37.88
Oxygen	9.39	Fixed carbon	49.91
Nitrogen	1.09	Ash	9.42
Sulphur	5.09		
Ash	9.42		
	100.00		100.00

Calorific value ..... 7,215 calories.

(a) Moisture in the air-dried sample about 3%.

Parts 2, 4, 6, 8 and 9 of the section were excluded from the sample. Parts 8 and 9 are rejected by the miner also but parts 6 and 4 are in-

cluded with the marketable coal. The sample, which measured 6 by 2 inches, was cut from a face that had been exposed less than a week.

Below is the record of a test made by the diamond drill at Alledonia in the southeast corner of section 22. This record has been placed at the disposal of the survey by Hon. Samuel L. Mooney, of Woodsfield.

	Ft.	In.
Surface	10	06
Yellow shale	2	00
Limestone, buff	3	00
Lime and shale, mixed	2	06
Hard dark green shale, flinty	2	03
Limestone	2	00
Limestone and shale, mixed	1	00
Hard dark gray shale rock, flinty	4	09
Limestone (with little shale)	9	06
Hard dark gray shale	1	06
Brown shale, hard	1	00
Fire clay	0	08
Soft clay shale	0	04
Black slate	0	01
Coal, Meigs Creek or No. 9	2	08
Gray, shale	1	03
Limestone	0	06
Hard sandstone	1	03
Sandy shale	0	03
Hard gray sandstone	4	09
Greenish shale	2	06
Limestone and shale with fossils	0	06
Greenish shale	1	00
Gray sandy shale	4	06
Part sandy shale and dark slate	3	06
Black slate	0	02
Coal	1	09
Dark shale	0	08
Limestone with fossils	0	06
Hard sandy shale, dark (sample)	0	03
Limestone with fossils	8	11
Cement limestone	4	06
Greenish shale	1	00
Limestone (sample)	4	09
Limestone and shale, mixed	1	00
Limestone	1	03
Hard dark shale	0	09
Limestone and shale, mixed	0	09
Sandstone and shale, mixed	1	06
Greenish shale	2	00
Gray sandstone	1	09
Gray soapstone	2	00
Hard gray shale	1	03
Limestone	5	04
Greenish shale	0	06
Limestone nodules	0	03
Greenish shale	1	03

	Ft.	In.
Brown shale	0	08
Coal, Pomeroy or Redstone or No. 8a	0	04
Hard gray shale	1	03
Blue limestone	1	05
Dark shale	0	05
Blue limestone	1	00
Gray limestone	4	00
Gray shale	0	04
Limestone	3	04
Limestone and shale, mixed	2	04
Limestone (sample)	1	09
Gray shale	0	06
Gray shale with limestone nodules	3	09
Fire clay	2	00
Coal, slaty	0	03
Dark slate	0	03
Roof Coal (Pittsburg)	0	10
Band fire clay	0	10
Coal, Pittsburg or No. 8	5	06
Fire clay	0	02
Calcareous shale, dark gray	3	09
Limestone with shale, hard	0	11
Limestone and sandy shale, mixed	0	11
Gray sandstone with iron	0	08
Gray shale and lime, mixed	0	06

Not only does this record show the Pittsburg coal in good thickness but the position also of the Pomeroy or Redstone and the Meigs Creek seams.

Wayne Township. In this township the Pittsburg coal is nowhere above drainage; neither is it mined and hence information must rest on the disclosures of the diamond drill.

Below is a record made in the valley of Captina Creek in the southeastern quarter of section 10. For this information the survey is indebted to Hon. Samuel L. Mooney, of Woodsfield:

	Ft.	In.
Surface, place of Meigs Creek or No. 9 coal	8	00
Limestone	1	00
Fire clay	3	06
Gray shale	3	04
Sandy shale	1	06
Hard black limestone	0	01
Gray shale	2	06
Sandy shale	6	00
Soft gray shale	8	03
Black slate	0	04
Coal	0	03
Dark shale	0	09
Limestone	2	00
Black shale	0	05
Limestone	5	02

	Ft.	In.
Black shale	0	03
Limestone	1	02
Dark shale	0	07
Cement rock	2	04
Limestone	2	02
Shale and lime, mixed	4	06
Sandy shale	1	06
Soft limestone	1	00
Sandy shale	1	00
Gray soapstone	4	00
Limestone	3	04
Soapstone and lime nodules	3	00
Coal and black slate, Pomeroy or Redstone	1	03
Fire clay	1	00
Gray shale	3	02
Black shale	1	00
Limestone	5	06
Limestone and shale	2	00
Limestone	3	00
Lime, fire clay	2	00
Gray shale with limestone nodules	3	00
Greenish shale	1	06
Dark shale, carbonaceous	3	02
Roof coal (Pittsburg)	0	10
Fire clay, band	1	00
Coal, Pittsburg or No. 8	5	07
Fire clay	4	01

A test was made in the northwest quarter of section 23, but the result was not favorable, the coal being only 2 feet 5½ inches thick, and this divided into two parts by a thin layer of shale. Above the coal is found a massive sandstone which probably explains the thinness of the seam. This test started above the horizon of the Meigs Creek seam. From drillings in adjacent townships it appears that this cut out is local, or at any rate, does not extend over a wide area.

Goshen Township. The coal in this township is everywhere under cover except a very small area in the northwestern section, No. 36. According to Professor Brown, the seam is there from 4½ to 5 feet thick and normal in structure.

In the southeast quarter of section 31, southwest corner of the township, the diamond drill showed only 3 feet 4 inches of coal. Above the seam lies a massive sandstone which very probably is responsible for the meagerness of the coal. This test is only about two miles from the one in Wayne township which disclosed less than 3 feet of coal and is doubtless included in the same basin.

The next test to be recorded was made in the northwest quarter of section 1, that is in the southeast corner of the township. For this and the preceding information indebtedness is acknowledged to Hon. S. L. Mooney.

	Ft.	In.
Surface	8	06
Yellow shale	1	00
Limestone	6	03
Green shale	2	00
Limestone	0	05
Green shale	0	03
Limestone with thin streaks of shale	4	06
Shale and sandy shale, mixed	1	06
Hard limy shale	1	00
Limestone	0	03
Greenish shale	0	06
Limestone	1	02
Green shale	0	06
Hard limy shale	0	08
Limestone	2	00
Hard limy shale	4	06
Greenish sandy shale	3	00
Between a limestone and blue core	5	06
Hard limy shale	0	09
Green shale	0	04
Limy shale, greenish	1	09
Hard limy shale	0	07
Limestone	1	05
Dark limy shale	1	00
Limestone	2	06
Hard dark limy shale	0	06
Limestone	6	00
Hard dark limy shale	0	06
Limestone	1	09
Green shale	0	10
Limestone	0	09
Green shale	0	09
Limestone	7	03
Limestone and shale, mixed	2	06
Blue core	0	09
Greenish limy shale	2	09
Limestone with little shale, mixed	1	03
Green shale	0	09
Gray shale	0	03
Blue core, or cement rock	3	00
Hard dark limy shale	0	09
Limestone mixed with shale	10	07
Limestone and dark shale, mixed	1	09
Coal, Meigs Creek or No. 9	3	02
Fire clay, sandy	0	09
Cement rock, dark	2	00
Limestone	6	09
Greenish shale	5	06
Dark gray slate	3	08
Dark gray slate, very soft	1	03
Coal	1	06
Slate	0	01
Coal	1	04

	Ft.	In.
Black slate	0	03
Limy shale	0	09
Cement rock	1	02
Limestone with fossils	0	07
Cement rock	1	07
Limestone	0	07
Black shale	0	02
Limestone	3	00
Black shale and limestone, mixed	0	09
Dark shale with fossils	0	06
Limestone	0	06
Cement rock	3	00
Limestone	1	03
Greenish limy shale	0	05
Green shale	0	10
Limestone	3	06
Greenish shale	0	06
Limestone with dark streaks	4	06
Greenish sandstone	1	06
Soft green shale	2	06
Gray shale	2	02
Limestone	3	00
Limy shale, soft	1	09
Slate and bone coal, mixed, Pomeroy or Redstone or No. 8a.	0	05
Fire clay	1	06
Dark shale	0	02
Limestone	0	07
Limy shale	2	03
Blue limestone	3	03
Limy shale	0	06
Limestone	0	09
Limy shale and limestone, mixed	1	08
Limestone	4	00
Dark gray shale, hard	0	04
Limestone	3	00
Limy shale and limestone, mixed	1	09
Soft clay shale	1	00
Limestone	0	06
Hard gray shale	1	00
Limestone	0	08
Green shale with limestone nodules	1	00
Gray shale with limestone nodules	1	03
Fire clay with dark streaks	1	09
Roof clay	0	05
Band	0	11
Coal, Pittsburg or No. 8	5	01
Fire clay	0	02
Hard dark limy shale	2	06

Warren Township. The Pittsburg coal underlies a large part of this township. In the northern part the headwaters of Stillwater Creek cut through the seam, and along the western edge the coal is exposed in a

number of narrow valleys. Especially is this true in the southwestern corner where the headwaters of Leatherwood Creek have formed deep and relatively wide valleys.

Near Barnesville the seam has long been mined for local use and is known as the Lower Barnesville coal. The Meigs Creek seam which is mined in the same locality is known as the Upper Barnesville coal.

The coal is mined for rairoad shipment in the southwestern part of the township.

Section 10 was taken in the Media Mine of the Colburg Coal Company of Columbus, located in section 21.

SECTION 10

	Ft.	In.
8. Draw slate,	0	6
7. Black shale,	0	1 ¾
6. Impure coal, rejected,	0	2 ¾
5. Breast coal,	0	11
4. Shale,	0	1
3. Bearing in coal, impure,	0	5
2. Shale,	0	¼
1. Brick and bottom coal,	3	0

The coal contains quite a number of local partings of shale and pyrites. Those that are persistent are shown in the section. The coal is quite hard and yields a red ash on burning. Its thickness ranges ordinarily from 4 feet 6 inches to 5 feet 3 inches, the average being about 4 feet 8 inches. The Draw slate is taken down in the entries but not in the rooms. Shaly sandstone lies above the Draw slate, the whole making a good roof.

The sections show the Breast coal unusually thin and a corresponding increase in the other divisions of the seam. These changes probably result from the locality being near the margin of the great basin in which this seam was formed.

This mine was opened about 1904 and when visited in 1907 was producing about 200 tons per day. Mining was done by hand but preparations were being made to use machines. Much of the coal has been shipped to the Great Lakes.

Chemical analysis and calorific value of Section 10:

Ultimate.		*Proximate.*	
Carbon	67.64	Moisture	4.47(a)
Hydrogen	5.17	Volatile Matter	37.53
Oxygen	10.43	Fixed carbon	46.99
Nitrogen	1.08	Ash	11.01
Sulphur	4.67		
Ash	11.01		
	100.00		100.00

Calorific value .....6,875 calories.

(a) Moisture in the air-dried sample about 3%.

Parts 4, 6, 7 and 8 of the section were excluded in sampling. Likewise these parts are rejected by the miner. The sample measured 6½ by 3½ inches and was cut from a fresh face. Part 2 of the section was a little above the average in thickness and hence the percentage of ash may be a trifle high.

Somerset Township. This forms the southwestern corner of the county. Within the limits of the township the coal varies more than elsewhere in the county. On the west side of the township the coal thins, but is mined at a number of places. In section 31 in the southwestern corner of the township, however, the coal is represented by a black streak only or is entirely wanting. The same is true along the southern margin of section 25. In such places the horizon of the coal is sometimes determined by the limestones.

The coal is everywhere below drainage in the township except in the two western tiers of sections. It has long been mined at Temperanceville and vicinity and in the valley in the northwestern corner of the township.

Section 11 was taken in the Jeffries bank at Temperanceville.

SECTION 11

	Ft.	In.
4. Shale, unmeasured,		
3. Coal,	0	10
2. Shale and pyrites, rejected,	0	¾
1. Coal,	3	0

The upper part of the seam contained three very thin pyrites and shale partings, and substantially the same is true of the lower or principal part of the seam. Occasionally films of pyrites are found in vertical cracks in the coal.

This section is another illustration showing how the Pittsburg coal loses its well known structure along the western margin of the field in this part of the state. The structure is more like that of the Meigs Creek seam than of the Pittsburg, though it undoubtedly belongs to the latter.

The Jeffries mine supplies the village and surrounding farmers with fuel. The coal is fairly hard and has a good roof. Below the coal the thick beds of limestone are found which are so common throughout the county. In fact these limestones are sometimes more persistent than the coal itself.

Chemical analysis and calorific value of Section 11:

Ultimate.		*Proximate.*	
Carbon	68.77	Moisture	4.08(a)(b)
Hydrogen	4.89	Volatile Matter	37.08
Oxygen	9.68	Fixed carbon	48.23
Nitrogen	1.10	Ash	10.61
Sulphur	4.95		
Ash	10.61		
	100.00		100.00

Calorific value ..... 6,931 calories.

(a) Sample slightly wet; Moisture possibly one-half per cent. high on this account.

(b) Moisture in the air dried sample about 3%.

Parts 2 and 4 of the section were rejected by both the miner and sampler. The sample measured 6 by 3½ inches, and was cut from a fresh surface.

Below is a record of a diamond drill test made at Somerton on the eastern side of the township:

	Ft.	In.
Surface	11	00
Soft yellow shale	1	06
Gray sandstone	61	02
Fire clay, limy	0	04
Slate and coal, Meigs Creek or No. 9	1	09
Limy shale, dark	0	05
Limestone	2	10
Hard dark shale	0	03
Limestone	0	06
Cement rock	1	06
Limestone	0	07
Limestone with fossils	0	06
Dark shale, hard	0	02
Limestone	3	00

	Ft.	In.
Black shale, hard	0	03
Limestone	1	03
Cement rock	3	06
Greenish sandy shale, with lime nodules	1	06
Clay shale	14	00
Greenish shale, sandy, with little lime	4	00
Lime or iron nodules	0	03
Gray sandy shale	5	00
Gray sandstone, place of Redstone coal	30	00
Dark gray shale with thin sandstone bands	2	09
Gray sandstone	1	03
Dark gray shale	0	03
Gray sandstone	2	03
Dark slate, with fossils	3	04
Slaty coal	0	03
Dark slate	2	11
Coal, Pittsburg or No. 8	4	07
Dark slate	0	02
Hard dark limy shale, fire clay	3	03
Shale with limestone nodules	0	09
Limestone	1	00

This shows 4 feet 7 inches of the Pittsburg seam, but less than two feet of the Meigs Creek while the Pomeroy or Redstone coal is wanting.

Another test was made in the northwest quarter of section 21 near the center of the township. This showed 4 feet 2 inches of the Pittsburg coal, but none of the Pomeroy or Meigs Creek seams. For these records the survey is indebted to Hon. S. L. Mooney of Woodsfield.

THE PITTSBURG COAL IN JEFFERSON COUNTY.

With the exception of Belmont county, Jefferson contains a larger quantity of the Pittsburg coal than any other county in Ohio. The coal rises rapidly to the north and west, so that north of the P. C. C. & St. L. R. R. the seam is found only in the tops of the highest ridges and hills.

While the coal has long been mined in this county it was not until the construction of the W. & L. E. R. R. about 15 years ago, which crosses the southern end of the county, that the production became large. Since that time other transportation lines have tapped the field making it one of the largest producers of fuel in the state. The following figures show the output of the county, nearly all of the coal being derived from the Pittsburg or No. 8 seam:[1]

Year	Short tons.
1897	751,848
1900	924,214
1901	1,322,305

[1] U. S. Geol. Survey.

1902	1,812,801
1903	2,479,211
1904	2,416,122
1905	3,269,376
1906	4,515,420

These figures show that the production has increased about sixfold in eight years. In 1905 Jefferson county ranked third in coal production in Ohio, being surpassed by Belmont and Athens counties only, but in 1906 the county took first place.

Thus far only a good start has been made in mining this seam, and the county will be a large producer for many years.

Mt. Pleasant Township. The Pittsburg coal underlies the whole of this township except the northern part where it has been eroded by Short Creek and Long Run. Along the latter stream in section 29, the coal disappears beneath the bed of the creek.

Dillonville, in the northeast corner of the township, is the principal mining point. In fact it is one of the best known mining centers in Eastern Ohio.

Section 12 was measured in Mine No. 2, of the Wheeling & Lake Erie Coal Mining Company at Dillonville.

The section of the Roof coal was taken in the main entry and according to the mine foreman, is abnormal, the usual succession above the Draw slate being 18 inches of coal, 3 feet of fire clay or rummel and above this limestone. The Roof coal is not mined.

This mine is reported to have been opened in 1893 and to have a daily capacity of 1,000 tons.

Chemical composition and calorific value of Section 12:

Ultimate.		*Proximate.*	
Carbon	69.56	Moisture	3.10(a)
Hydrogen	5.22	Volatile Matter	37.92
Oxygen	10.77	Fixed carbon	49.46
Nitrogen	1.10	Ash	9.52
Sulphur	3.83		
Ash	9.52		
	100.00		100.00

Calorific value ..... 7,153 calories.

(a) Moisture in the air-dried sample about 3%.

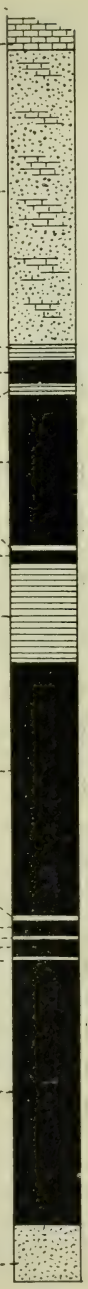
This sample includes parts 2 and 6 of the section, that is the Breast, Brick and Bottom coal. These are the only parts saved in mining.

The sample was taken in a new room under model conditions, and hence is unusually satisfactory. The width of the sample was 3½ inches and the depth 4 inches.

Smithfield Township. This township is twice the size of Mt.

SECTION 12

		Ft.	In.
11.	Limestone, unmeasured,		
10.	Clay, with some limestone,	3	0
9.	Shales,	0	2
8.	Roof coal, — Coal,	0	2 ½
	Shales,	0	1½
	Coal,	1	6
	Shales,	0	¾
	Coal,	0	1 ½
7.	Draw slate, soapstone,	1	0
6.	Breast coal,	2	6 ½
5.	Parting, ⅝		
4.	Bearing in coal, — Coal,	1 ⅝	
	Parting,	⅝	
	Coal,	2 ¼	
3.	Parting, ⅜		
2.	Brick and bottom coal,	2	8
1.	Clay, reported thickness,	0	7



Pleasant and hence contains a larger area of the Pittsburg coal though in the latter the coal lies lower in the hills.

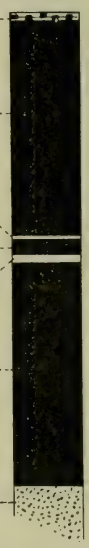
A splendid exposure of the Ames limestone is found in the bed of Short Creek at Adena. The formation is highly fossiliferous, several feet thick and lies about 175 feet below the Pittsburg coal.

Short Creek crosses the southwest corner of the township, exposing the coal along its banks. Several other streams have cut deep trenches through the coal making exposures numerous and mining comparatively easy. Most important of these streams is Piney Fork which crosses the township from the northwest to the southeast corner. The valleys of these streams are all narrow and hence the quantity of coal removed relatively small.

Section 13 was taken in the Crow Hollow Mine of the United States Coal Company, about two miles southeast of Smithfield.

SECTION 13

	Ft.	In.
7. Bone coal, not mined,		1
6. Breast coal,	2	1½
5. Parting,	0	⅜
4. Bearing in coal,	0	1⅝
3. Parting,	0	1
2. Brick and bottom coal,	2	2½
1. Clay, unmeasured,		



The Roof coal is reported to be uncertain, sometimes measuring one foot but usually less and occasionally wanting.

This mine has been in operation about five years and has a reported maximum daily capacity of 2,500 tons.

Chemical analysis and calorific value of Section 13:

Ultimate.		*Proximate.*	
Carbon	72.43	Moisture	4.96(a)
Hydrogen	5.37	Volatile Matter	34.51
Oxygen	12.67	Fixed carbon	54.08
Nitrogen	1.33	Ash	6.45
Sulphur	1.75		
Ash	6.45		
	100.00		100.00

Calorific value ..... 7,277 calories.

(a) Moisture in the air-dried sample about 3%.

The sample taken included parts 2 and 6 of the section. The bone

coal (part 7) is not mined, and parts 3, 4 and 5 are rejected by the miners.

Section 14 represents the coal in a mine of the United States Coal Company in the northwestern corner of the township.

SECTION 14

	Ft.	In.
7. Draw slate, soapstone,	0	9
6. Breast coal,	1	11
5. Parting,	0	1
4. Bearing in coal,	0	1
3. Parting,	0	¾
2. Brick and bottom coal,	2	2
1. Clay, unmeasured,		

No lenses of pyrites were found in this section but elsewhere in the mine they are quite common. The Roof coal was not seen but was reported to vary from 8 to 12 inches in thickness and to be inferior in quality.

This mine has a capacity of 1,600 tons per day and employs 350 men. The mine has four entries, but the coal is all handled at one tipple. Two electric motors are used to haul the coal.

Chemical analysis and calorific value of Section 14:

Ultimate.		*Proximate.*	
Carbon	71.34	Moisture	4.30(a)
Hydrogen	5.18	Volatile Matter	35.28
Oxygen	11.39	Fixed carbon	52.54
Nitrogen	1.20	Ash	7.88
Sulphur	3.01		
Ash	7.88		
	100.00		100.00

Calorific value ..... 7,144 calories.

(a) Moisture in the air-dried sample about 3%.

The sample included parts 2 and 6 of the above section, the rest

having been rejected by the miners as well as by the sampler. The sample taken was 6½ inches wide and 1½ inches deep.

In the northeast quarter of section 22 Professor Brown measured the following interesting section:[1]

	Ft.	In.
Shales, exposed	10	0
Pomeroy coal	2	1
Clay streak		
Limestone	2	0
Clay shale	11	0
Roof coal: Coal	2	6
Roof coal: Shale	0	2
Roof coal: Coal	0	8
Draw slate (clay or soapstone)	1	0
Black slate	0	1
Breast coal	2	4
Parting	0	¼
Bearing in coal	0	1½
Parting	0	½
Brick coal	1	3
Shale parting with some pyrites	0	¼
Bottom coal	1	0
Clay. Unmeasured.		
Limestone.		

The character of the roof in this mine is well shown by the following from Professor Brown's report: "This mine has been opened fifty-seven or fifty-eight years, and although in a very bad place and very poorly cared for, the roof, as far as examined, showed no signs of giving away. Many of the rooms are twenty-five to thirty feet span, and the posts have rotted away, yet the roof remains intact."

The sections of the coal already given can be duplicated in nearly every part of the township. Everywhere the structure of the seam shows the same features and approximately the same thickness. Hence no additional sections will be given.

Sections of the Roof coal are not easy to get because this part of the seam is rarely shown. In fact one has to hunt for places where this coal has fallen, in order to secure a measurement. The following additional thicknesses of this part of the seam may be reported:[2]

	Ft.	In.
South side, section 33	0	2-4
Southwest quarter, section 29	1	6
Northwest quarter, section 22	1	10

These figures indicate a marked variation in the thickness of this part of the seam. It is nowhere mined in the township at present, though it does not seem probable that coal operators will long allow from one to two feet of good coal to waste, especially when it can be

[1] Geol. Sur. of Ohio. Vol. VI., p. 601-2.

[2] Vol. VI., pp. 600-1.

easily saved. As is well known the Roof coal of this seam is now quite extensively mined in Pennsylvania.

Professor Brown found two blossoms of coal in section 28. One of these is 22 feet above the base of the Pittsburg seam, and is to be correlated with the Redstone coal of Pennsylvania and the Pomeroy coal of Southern Ohio. The higher blossom lies 101 feet above the same base and represents the Meigs Creek coal of Ohio and the Sewickley of Pennsylvania. As is elsewhere stated, this coal is not of workable thickness in Jefferson county. (Page 141).

In the southwestern quarter of section 15 Professor Brown found the Pomeroy or Redstone coal 12 inches thick, and 29 feet above the bottom of the Pittsburg seam. Not so much as a blossom of the Meigs Creek coal was found in this hill, though the conditions for exposure were favorable:[1]

From what has been said it is plain that Smithfield township contains a large and valuable deposit of the Pittsburg coal. The territory promises to be an important mining district for fifty years or more.

Warren Township. This township which lies east of Mt. Pleasant and the southern half of Smithfield contains a large body of the Pittsburg coal. The township is crossed by Short Creek which has cut a deep, though rather narrow valley, and fronts on the Ohio River. While the coal dips toward the river yet it is high in the hills on the river front owing to the depth of the valley.

In the mine of the Ohio and Pennsylvania Coal Company at Yorkville, the coal was found as shown in Section 15.

SECTION 15

	Ft.	In.
6. Breast coal,	2	7
5. Parting,	0	½
4. Bearing in coal,	0	1¼
3. Parting,	0	½
2. Brick and bottom coal,	2	5½
1. Clay, unmeasured,		

[1] Vol. VI, p. 601.

The Breast coal includes one inch of Bone coal which is sometimes rejected. The Draw slate, lying above the Breast coal, was reported to vary from 3 feet to nothing in thickness. In mining, the lower 2 to 3 inches of the Bottom coal are not removed owing to its reported inferiority.

While no pyrites was found in this section, an examination of coal mined showed considerable of this substance.

As the section shows the Brick and Bottom coal are not separated by a parting. The capacity of this mine was reported at 700 tons of run of mine and 400 tons of screened coal per day.

The following section of the Roof coal was made in an entry of this mine:

	Ft.	In.
Coal	0	5
Shale	0	9
Coal	0	8
Shale	0	7
Coal	0	10
Draw slate.		

Only six feet from this place the shales had disappeared leaving a bed of coal about 20 inches thick.

Chemical analysis and calorific value of Section 15:

Ultimate.		*Proximate.*	
Carbon	71.03	Moisture	3.13(a)
Hydrogen	5.38	Volatile Matter	37.88
Oxygen	10.09	Fixed carbon	50.77
Nitrogen	1.26	Ash	8.22
Sulphur	4.02		
Ash	8.22		
	100.00		100.00

Calorific value ..... 7,233 calories.

(a) Moisture in the air-dried sample about 3%.

The sample taken was from parts 2 and 6, these being the only ones marketed, and was 6 inches wide and 2 inches deep.

Section 15a was measured in a mine of the Glenn's Run Coal Company.

At 5 and 11 inches above the bottom, two dirt streaks were noticed; one measured about one-fourth and the other three-eighths of an inch in thickness. Neither is thrown out in mining. The coal is not bright in appearance, but is quite free from pyrites.

SECTION 15a

	Ft.	In.
6. Breast coal,	2	4
5. Parting,	0	⅜
4. Bearing in coal,	0	1
3. Parting,	0	⅝
2. Brick and bottom coal,	2	1
1. Clay, unmeasured,		

Chemical analysis and calorific value of Section 15a:

Ultimate.		*Proximate.*	
Carbon	71.18	Moisture	4.57(a)
Hydrogen	5.06	Volatile Matter	32.40
Oxygen	11.89	Fixed carbon	54.03
Nitrogen	1.32	Ash	9.00
Sulphur	1.55		
Ash	9.00		
	100.00		100.00

Calorific value ..... 7,105 calories.

(a) Moisture in the air-dried sample about 3%.

This sample included parts 2 and 6 of the section.

The following section of the coal was measured in the southwest quarter of section 28 on the bank of Little Short Creek:[1]

	Ft.	In.
Roof coal	2	2½
Draw slate (clay)	0	4
Breast coal	2	2
Clay parting	0	1
Bearing in coal	0	2
Black shale	0	½
Brick coal	1	3
Parting		
Bottom	1	2
Clay	0	4

Limestone, unmeasured.

[1] Vol. VI, p. 603.

As has already been stated the coal is high in the hills along the river front. Thus at Yorkville the seam is 192 feet above the C. & P. Railroad tracks; at Tiltonville, one mile farther north, 212½ feet; at Portland Station, less than two miles farther north, 272 feet, and in the southeast quarter of section 8, 297 feet.

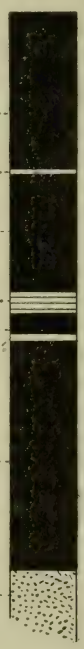
Near Portland Station Professor Brown found the Ames limestone less than a foot thick and 197 feet below the Pittsburg coal. Farther north the limestone thickens and the interval between it and the coal increases, becoming 213 feet in section 8.

Wells Township. This township, lying north of Warren, contains a large area of the Pittsburg coal. The seam has suffered more from erosion than in any other township thus far considered. The valleys are numerous and deep, and the coal lies near the tops of the hills.

In the mine of Dewland Cox & Sons, at Brilliant, the coal was found as shown in Section 16.

SECTION 16

		Ft.	In.
6. Breast coal,	Coal,	1	7
	Parting,	0	¼
	Coal,	1	2
5. Parting,		0	2½
4. Bearing in coal,		0	2½
3. Parting,		0	¾
2. Brick and bottom coal,		2	3½
1. Clay, unmeasured,			



The abnormal thickness of the parting at the top of the Bearing in coal is local. A few feet away the thickness is less than a half inch.

This mine supplies the village Brilliant and the surrounding country with fuel. Four miners are employed during the busy season.

Chemical analysis and calorific value of Section 16:

Ultimate.		*Proximate.*	
Carbon	68.01	Moisture	4.89(a)(b)
Hydrogen	5.03	Volatile Matter	33.10
Oxygen	11.29	Fixed carbon	51.55
Nitrogen	1.12	Ash	10.46
Sulphur	4.09		
Ash	10.46		
	100.00		100.00

Calorific value .....6,953 calories.

(a) Sample slightly wet. Moisture possibly one per cent high on this account.

(b) Moisture in the air-dried sample about 3%.

This section included parts 2 and 6. The mine had much water so that sampling cloth and sample were somewhat wet.

The coal rises rapidly to the north, being 343 feet above the C. & P. Railroad track at Brilliant. At this village the Ames limestone is five feet thick and lies 238 feet below the Pittsburg coal:[1]

Wayne Township. This township contains quite an area of coal near the tops of the high hills and ridges south of the P. C. C. & St. L. Railroad.[2]

Section 17 was taken in the McFadden mine of the Wayne Coal Company.

All the seam below the Draw slate is mined and shipped, the partings being too thin to be sorted out. Occasional lenses of pyrites are found and rejected.

Practically the entire output of this mine is shipped to Dennison and used in the yards of the Pennsylvania railroad.

The coal is reported to vary in thickness from 4 feet 2 inches to 4 feet 10 inches and to be similar in structure to the same seam farther south. Perhaps the seam contains more pyrite than is found in the townships to the south.

Chemical analysis and calorific value of Section 17:

Ultimate.		*Proximate.*	
Carbon	70.68	Moisture	5.05(a)
Hydrogen	5.32	Volatile Matter	35.88
Oxygen	12.19	Fixed carbon	51.12
Nitrogen	1.25	Ash	7.95
Sulphur	2.61		
Ash	7.95		
	100.00		100.00

Calorific value .....7,147 calories.

(a) Moisture in the air-dried sample about 3%.

[1] Data on this township compiled from Prof. Brown's report. Vol. VI, pp. 599-600.

[2] Data compiled from Prof. Brown's report. Vol. VI, p. 597.

SECTION 17

		Ft.	In.
8. Roof coal, reported thickness,		0	10
7. Draw slate,		0	10
6. Breast coal,	Coal,	1	2
	Shale,	0	⅛
	Coal,	0	1
	Shale,	0	⅛
	Coal,	0	3
5. Bearing in coal, coal and shale,		0	1½
4. Brick coal,		0	6
3. Coal with ½ inch of shale,		0	2½
2. Bottom coal,		1	10
1. Clay, unmeasured,			

With the exception of parts 1, 7 and 8, the entire section was included in the sample, since all except these parts are marketed. The mine was very wet and in consequence the sample was taken in an entry. The sample was 6 inches wide and 2 inches thick.

Other Townships. Small areas of the Pittsburg coal are found in Island Creek, Cross Creek, Steubenville, Salem, Springfield, Ross and Knox Townships. In each of these the area of coal is small, and of importance only as a local supply. The seam possesses the same structural features that are found in the southern part of the county, though the coal is usually thinner, and, because of its poorer covering, more weathered.

THE PITTSBURG COAL IN HARRISON COUNTY.

The western margin of the Pittsburg coal underlies the higher parts of the eastern portion of Harrison county, being found in nine townships. The seam once formed a continuous stratum over this area, that which remains being the portion which has escaped stream erosion.

Until very recently the coal was mined for local use only, for which it has had a steady demand for perhaps three quarters of a century. Quite recently two or three mines for railroad shipment have been opened, and work will progress more rapidly in the future.

Southward the seam extends in Belmont county and eastward into Jefferson, in both of which it is extensively mined. A few small outliers of the coal are found in the hills of Carroll county to the north.

Short Creek Township. The coal in this township has been divided into three strips by two streams, Short Creek and Little Short Creek. The southernmost of these three strips, comprising as it does two rows of sections extending east and west across the township, is by far the largest. The coal has not been mined in this strip except along the north side where the seam outcrops in the deep valley of Little Short Creek. Here a number of country banks have long existed. Quite recently a mine for railroad shipment has been opened in the northeast corner of the township.

Section 18 was taken in a mine on the S. P. Dunlap farm in the northwestern part of the township.

SECTION 18

	Ft.	In.
7. Roof coal, reported,	2	0
6. Draw slate, soapstone, reported,	1	2
5. Breast coal,	2	1
4. Parting,	0	½
3. Bearing in coal,	0	2½
2. Parting,	0	¾
1. Brick and bottom coal,	1	10½

This mine supplies a local demand among farmers. It is worked regularly in winter but only an occasional day in summer.

Chemical analysis and calorific value of Section 18:

Ultimate.		*Proximate.*	
Carbon	70.49	Moisture	6.54(a)(b)
Hydrogen	5.70	Volatile Matter	35.48
Oxygen	13.66	Fixed carbon	51.24
Nitrogen	1.22	Ash	6.74
Sulphur	2.19		
Ash	6.74		
	100.00		100.00

Calorific value .....7,061 calories.

(a) Sample wet. Moisture approximately 2% high on this account.
(b) Moisture in the air-dried sample about 3%.

Section 19 was measured in the mine of The Adena Mining Company near Adena in the northeastern part of the township.

SECTION 19

		Ft.	In.
11. Roof coal,	Coal,	1	0
	Parting,	0	¼
	Coal,	0	½
	Parting,	0	¼
	Coal,	0	¼
10. Draw slate, clay,		0	10
9. Bone coal, not mined,		0	1½
8. Breast coal,		2	5½
7. Parting,		0	½
6. Bearing in coal,		0	2
5. Parting,		0	½
4. Brick coal,		1	½
3. Pyrites layer,		0	1¼
2. Bottom coal,		0	11½
1. Clay, unmeasured,			

The layer of pyrites shown in this section is quite persistent though not always present. The daily capacity of the mine is about 600 tons.

Chemical analysis and calorific value of Section 19:

Ultimate.		*Proximate.*	
Carbon	71.20	Moisture	4.18
Hydrogen	5.36	Volatile Matter	36.95
Oxygen	11.13	Fixed carbon	50.65
Nitrogen	1.26	Ash	8.22
Sulphur	2.83		
Ash	8.22		
	100.00		100.00

Calorific value .....7,160 calories.

(a) Moisture in the air-dried sample about 3%.

This sample included parts 2, 4 and 8 of the section. Part 9 is not mined and parts 5, 6 and 7 are rejected by the miners.

Green Township. The Pittsburg seam in this township consists of a number of long narrow strips lying near the summit of high ridges. It has long been mined in a small way for local use, at a number of places, and within the past few years has been worked more extensively. Near the station Ginther, the following section was measured in the mine of the Pittsburg Block Coal Company:

	Ft.	In.
Roof coal, not mined	0	8
Draw slate (Soapstone)	1	0
Top or Breast coal	2	0
Shale and coal	0	2
Brick coal	1	1
Shale parting	0	¼
Bottom coal	1	2
Soapstone	0	4
Limestone, unmeasured.		

The thin band of coal and shale lying between the Top or Breast and the Brick coal represents the Bearing in seam.

German Township. This township, situated in the extreme northeast corner of the county, contains even less coal than is found in Green township. In fact the seam is present in only the highest hills. The following section of the coal was measured near the village of Jefferson, the altitude of the mine being about 1,237 feet:

	Ft.	In.
Shale, unmeasured.		
Bone coal. Not mined	0	2
Top or Breast coal	2	0
Shale and coal	0	3
Brick coal	0	9½
Shale parting	0	¼
Bottom coal	1	1
Fire clay	0	4
Limestone, unmeasured.		

Doubtless the three inches of coal and shale lying between the Top and Brick coals represent the Bearing in seam so well shown along the Ohio River and in Pennsylvania and West Virginia.

Rumley Township. This township, which lies west of German, contains very little of the Pittsburg coal, and the greater part of that lies in the hill-tops in the northeast corner of the township.

Archer Township. Two high and narrow ridges cross this township from the northwest to the southeast. These contain a small quantity of the coal under consideration. It is mined in a small way at a number of places, but can never be a large source of fuel. A small arm of the seam extends westward into Archer Township.

Cadiz Township. This township, situated on the divide between Stillwater and Short Creeks, contains a large quantity of coal, though it is confined to the high ridges. The seam has long been worked, especially in the vicinity of Cadiz.

Section 20 was measured in the mine of the Glover Coal Company at Cadiz.

SECTION 20

		Ft.	In.
9.	Shales, unmeasured,		
8.	Breast coal, — Coal,	0	7
	Breast coal, — Pyrites layer, often wanting,	0	8
	Breast coal, — Coal,	1	6
7.	Shale,		
6.	Bearing in coal,	0	2
5.	Shale,		
4.	Brick coal,	1	3
3.	Shale,	0	4
2.	Bottom coal,	1	1
1.	Fire clay, reported thickness,	0	6

Pyrites concretions are found in the Brick coal. These sometimes become 3 or 4 inches thick and 2 feet in diameter. The coal is sold almost exclusively in the neighborhood but occasionally a carload is shipped.

Chemical analysis and calorific value of Section 20:

Ultimate.		*Proximate.*	
Carbon	67.70	Moisture	3.83(a)
Hydrogen	5.09	Volatile Matter	36.70
Oxygen	10.68	Fixed carbon	48.59
Nitrogen	1.27	Ash	10.88
Sulphur	4.38		
Ash	10.88		
	100.00		100.00

Calorific value ..... 6,864 calories.

(a) Moisture in the air-dried sample about 3%.

Parts 1, 5, 6, 7 and 9 of the above section were rejected in sampling. The sample taken was 4 inches wide and 2 inches deep.

Athens Township. This contains in proportion to its size, a larger acreage of the Pittsburg coal than any other township in the county. In the southeastern part of the township the coal is below drainage and so is not mined. In the western part of the township, a number of farmers work the seam, and it is there the main reliance for fuel.

Section 21 was taken on the John Edwards farm, northeast quarter of section 1.

SECTION 21

	Ft.	In.
Roof coal,	0	10
7. Draw slate, soapstone,	0	10
6. Breast coal,	2	0
5. Bearing in coal, (coal and shale)	0	2
4. Brick coal,	1	3
3. Shale,	0	¼
2. Bottom coal,	1	½
1. Clay, unmeasured,		

The top coal is not mined and was not included in sample. In

mining the Brick coal is undercut, and the Bottom coal shot. Later the Breast coal is knocked down.

Chemical analysis and calorific value of Section 21:

Ultimate.		*Proximate.*	
Carbon	72.22	Moisture	5.98(a)
Hydrogen	5.44	Volatile Matter	34.35
Oxygen	13.71	Fixed carbon	53.70
Nitrogen	1.31	Ash	5.97
Sulphur	1.35		
Ash	5.97		
	100.00		100.00

Calorific value .....7,202 calories.

(a) Moisture in the air-dried sample about 3%.

The sample included parts 2, 3, 4 and 6 of the section, and was 4 inches wide and 2½ inches deep. On the Burney farm in section 12, the following measurement of the coal was made:

	Ft.	In.
Soapstone. Unmeasured.		
Roof coal, not mined	1	0
Soapstone	1	0
Top or Breast coal	1	3
Bearing in coal and shales	0	4
Brick and Bottom coals	3	6

The structure of the seam in this section shows a change over that of preceding sections, the Top or Breast coal thinning and the Brick and Bottom divisions thickening.

No extensive mining needs be expected in this township until it is penetrated by a railroad. It contains a large quantity of valuable fuel and will be ere long a busy mining center.

Moorefield Township. This township, lying west of Athens, contains a few thousand acres of coal lying in the highest ridges. It has long been mined by farmers, and will be their main reliance for fuel for many years.

Nottingham Township. This contains a few small outliners of coal extending west from Cadiz township and north from Moorfield. It is mined by farmers, but can never have more than a local value.

THE PITTSBURG COAL IN GUERNSEY COUNTY.

From Belmont county the Pittsburg coal extends west into Guernsey. However, it is found only in the higher ridges and hills and the area is small. Nowhere is it mined for railroad shipment.

Millwood Township. This township contains a larger area of the Pittsburg coal than any other township in the county. The seam is well shown in the ridges on the north and south sides of Leatherwood Creek

where it has long been mined for local use. The villages Quaker City and Salesville rely on these mines as do the surrounding farmers.

The Ames limestone is exposed in the valley at Quaker City, and was found by Professor Brown to be 190 feet below the coal. In the northeast quarter of section 20, near this village, Professor Brown found the coal as follows:[1]

	Ft.	In.
Shale, unmeasured.		
Shaly coal, rejected	0	3½
Coal	0	10
Shale and pyrites	0	¾
Coal	1	8
Clay	0	¾
Coal	1	4
Clay, unmeasured.		

The section shows the characteristic structure of the seam, as found farther east, wanting. The Bearing in coal is absent, and the Breast coal is abnormally thin. The shales above the coal are overlain with a heavy mass of sandstone. Occasionally the shales are wanting and then the sandstone rests directly on the coal.

Oxford Township. This lies north of Millwood township and contains a smaller area of coal. Near Fairview in the eastern part of the township Professor Brown reports the coal as follows:

	Ft.	In.
Shale, unmeasured.		
Coal	1	0
Shale or clay	0	4½
Coal	1	3
Parting, thin.		
Coal	1	0
Fire clay, unmeasured.		

Here the Bearing in coal is wanting, its place being taken by the 4½ inches of shales or clay. The coals below this bed represent the Brick and Bottom parts of the seam.

Londonderry Township. This township lies north of Oxford. The coal in question is found only in the tops of the highest hills and is of small value, even locally. The best deposit is found in sections 4, 5, 10 and 11 in the southeast corner of the township.

Other Townships. The Pittsburg coal is found in Spencer, Wills and Richland townships, but the quantity of coal is small. It is occasionally found in the tops of the highest hills, but can scarcely be rated as even a local source of fuel.

[1] Geol. Sur. of Ohio, Vol. VI, p. 623.

THE PITTSBURG COAL IN MUSKINGUM COUNTY.

The Pittsburg coal is restricted to the southeastern part of this county,—east of the Muskingum River and south of the Baltimore & Ohio Railroad, with the exception of a very small area in Union township.

The coal is thin, but very evenly developed over this area, with the exception of the southern part where it is wanting. It lies usually from 80 to 85 feet below the Meigs Creek coal, is generally about 30 inches thick, and is reported to be of better quality than the higher seam.

Blue Rock Township. This township lies directly north of Bloom township, Morgan county, and in the southern half, as in the northern half of Bloom, the Pittsburg coal is absent. In the ridge south of Kent's Creek near Keifer and east to the township line, the coal is present, but the blossom is rarely seen, owing to the slipping of the overlying shales. It has not been worked here and its thickness is unknown. In the extreme northeast corner of the township, in section 1, it was opened several years ago on the land of Edward Smith where it was reported 22 inches thick. It also occurs in the northern part of Meigs township to the east.

Salt Creek Township. The Pittsburg coal is found only in a narrow ridge in the extreme southeastern corner of this township but has been opened at a number of points. On the old J. W. Reasoner farm it was reported two feet thick. There it lies only 65 feet below the Meigs Creek coal, barometer measurement.

Rich Hill Township. In the southwestern part of this township, northeast quarter of section 31, the Pittsburg coal was formerly worked on the farm of Rachel Eckelberry where the following section was reported:

	Ft.	In.
Coal	0	6
White shale	0	6
Coal	1	10

In the southwestern corner of the township and along the western outcrop of the seam, this coal has been worked in years past at numerous points, and with the exception of the southwestern corner where it is a little thinner, is everywhere reported 30 inches thick, and is known as "the 30-inch vein." Very few of the banks are now in operation, however, as the farmers prefer the more easily worked but inferior Meigs Creek coal. The following section given by Brown shows the relation of this coal to the Meigs Creek and to the Ames limestone. It is from sections 21 and 22 near the center of this township.[1]

[1] Geol. Sur. of Ohio, Vol. V., p. 1071.

	Ft.	In.
Meigs Creek coal	4½	0
Not exposed	81	0
Pittsburg coal	0	30
Not exposed	151	0
Ames or Crinoidal limestone about	2	0

In the northeastern part, it is reported 30 inches thick but has been mined very little. In the eastern and southeastern part it is not worked and is probably thinner.

Union Township. The Pittsburg coal lies very near the top of the ridges in this township. To the north and west the seam is much thinner, and is probably not far from the northwestern limit of deposition. Over the central and southern parts it is reported about 30 inches thick. It was measured on the land of J. B. Morrow, one and one-half miles southeast of Norwich where it is 30 inches thick. A line of small outliers extends west from the main ridge at this place, and on one of these, on the farm of John McGee, one and one-half miles south of Norwich, the coal is said to be only 10 inches thick. It was not seen or reported north of the B. & O. R. R. tracks, although the ridge is high enough to hold it.

On the farm of Frank Wilson, section 12, two miles southwest of New Concord, the coal is reported as cannel, but it soon passes into soft coal as is shown on the opposite side of the ravine from the cannel exposure. On the farm of Samuel Noble, two and one-half miles south of New Concord, the coal is reported 46 inches thick, and all cannel except about one foot of soft coal at the top. This is probably the greatest thickness of this seam in Muskingum county but it is only a very local deposit, as it thins rapidly to 30 or 32 inches.

THE PITTSBURG COAL IN NOBLE COUNTY.

The coal in question is of very little value in this county. It is mined in one part only, namely a small area in the extreme northeastern corner. Throughout part of the county the seam is not represented by even a black streak.

The area of workable coal referred to in the above paragraph is in Beaver township. It lies north of Beaver Creek and east of a line drawn from Batesville to Quaker City. At present the seam is worked on the Deal farm in the southwest quarter of section 5 and on the Douglass farm in the southeast quarter of section 11. Both mines are small, supplying one or more farmers. Outside of this area the seam is of no importance in Noble county.

THE PITTSBURG COAL IN MONROE COUNTY.

This seam outcrops in the northwest corner of the county, especially in Malaga township. Farther west the coal thins. It is reported to have been mined many years ago in the vicinity of Calais in Seneca township, but the coal there is very thin and of little or no value.

Malaga Township. The coal is above drainage in the western third only of this township. It is mined on the George Neuhart farm in the southwest quarter of section 24. The proprietor reports the coal three feet thick with a sandstone roof and limestone below. Westward the coal thins rapidly and does not appear of value. To the east in section 24, the coal goes under cover.

In the next valley to the south the coal is of more value. It has long been mined in a small way in sections 28 and 29 on the Clause, Burkhart and Reimensnider farms. Everywhere the coal lies just above the limestone, which, in fact, is more persistent than the coal itself.

Below is a section of the coal on the Clause farm in section 28, as furnished by the proprietor:

		Ft.	In.
Roof Coal	Coal	0	6
	Shale	0	½
	Coal	0	6
	Shale	0	½
Clay		0	10
Coal		1	6
Clay		0	1
Coal		0	6
Clay		0	2
Coal		0	6
Clay		1	0

Limestone, unmeasured.

On the Burkhart farm, adjoining the Clause, the coal was reported as follows:

Shale, unmeasured.	Ft.	In.
Coal with shale partings	2	0
Shale, hard	1	0
Coal	1	0

Shale, unmeasured.

In section 33 in the southwest corner of the township, the coal has been stripped in the bed of the creek and was reported 18 inches thick.

Westward from the localities given, the coal thins rapidly and within a mile is too thin to work.

Summit Township. The Pittsburg coal outcrops in the valley at Burkhart, and is reported to have been stripped, having a thickness of 22 inches. There as elsewhere, the limestones below the coal are more conspicuous than the coal itself.

The Pittsburg coal is known to exist in the southern part of Belmont county almost to the county line. From this it is reasonable to conclude that the seam underlies the adjacent part of Monroe county. It is reported by oil drillers near Jerusalem along the Malaga-Sunbury township line, but is not reported in the oil field east of Woodsfield.

The coal has been reported on the basis of diamond drill tests at various places in the northeast corner of the township; in section 35 of Sunbury township, 5 feet; in section 28 of Switzerland township, 5 feet, 3 inches; in Section 32 of Salem township, 5 feet, 8 inches.

Several diamond drill tests have been made opposite Monroe county in or near the valley of the Ohio River in West Virginia.[1] In the southern part of Marshall county, near the village of Proctor, the coal measures 5 feet, 11 inches. This is opposite the northern part of Ohio township, Monroe county.

A test was made on the Higgs farm near Franklin Station, north of Proctor, and a thickness of 7 feet, 9 inches, found. Of this, 2 feet belongs to the Roof coal. This test was opposite Salem township, Monroe county. Other wells drilled in the same general territory gave similar results. The presence of the Pittsburg coal in large thickness in the valley of the Ohio certainly warrants the conclusion that the seam may be found in the adjacent part of Monroe county.

THE PITTSBURG COAL IN WASHINGTON COUNTY.

This seam is found in several townships of Washington county, but is nowhere an important source of fuel. It is at its best in Salem township, where it has long been mined in a very small way by farmers.

The seam is 2 feet or more in thickness in parts at least of the following townships,—Salem, Fearing, Liberty and Ludlow. Throughout this territory the coal is known as the "Limestone" or "Lower Salem," because of the limestones associated with it and from its being mined near the village, Salem, where a higher seam, the Meigs Creek is also worked.

As has already been stated this seam is not at present an important source of fuel in this county. In fact it is safe to say that it can never become a large producer. It is interesting geologically but not commercially.

The position of the seam is about 90 feet below the Meigs Creek coal which is the most important seam in Washington county.

In the eastern townships bordering the Ohio river, the Pittsburg coal is everywhere below drainage. Professor White states that it is from 135 to 150 feet below the river at Sistersville.[2]

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[1] West Va. Geol. Sur. Vol. II, pp. 131-135.

[2] W. Va. Geol. Sur. Vol. I, p. 356.

The following record of Mehrley Well No. 10 opposite Sistersville, shows the relation of this coal to several important underlying formations.[1]

	Thickness of Formation.	Total Depth.
Unrecorded	175	175
Washington coal	3	178
Unrecorded	407	585
Pittsburg coal	5	590
Unrecorded	430	1,020
"Cow Run" sand	50	1,070
Unrecorded	55	1,125
Freeport sand	150	1,275
Unrecorded	365	1,640
Big Lime or Mountain limestone	97	1,737
Big Injun Sand	78	1,815

This shows an interval between the Pittsburg coal and the Big Injun sand of 1147 feet. Other wells drilled in the same locality[2] show that the Berea grit lies 500 feet below the top of the Big Injun sand, making the interval between the Pittsburg coal and Berea grit about 1650 feet. At Macksburg in the extreme northern part of the county this interval is only 1560, but at Flints Mills, nearly midway between Macksburg and Sistersville the interval is 1820 feet.[3] The latter figure is abnormal.

These intervals are helpful in an area like this where so often no well marked formation exists above drainage. On this basis the Pittsburg coal is about 250 feet below the valley of the Ohio at Marietta; and is everywhere under cover in that valley, above Marietta, except near Newport where the great Burning Springs anticlinal crosses the river bringing the Pittsburg coal and even lower formations above the level of the river.

Salem Township. The Pittsburg coal is found outcropping in all the deeper valleys of this township. About one mile northwest of Warner, on lot 38, the seam measures one foot five inches in thickness. It does not appear to be of workable thickness anywhere on the west side of Duck Creek in this township. Eastward and southward it thickens. The following section of this coal was measured on the J. W. Haas farm, about one-half mile north of Warner:

	Ft.	In.
Limestone. Unmeasured		
Shale	2	6
Coal	2	0

In the hills back of the village of Salem, Andrews found the seam 2 feet 6 inches thick.[4] It has been opened on several farms in

[1] Ibid. p. 356.

[2] Geol. Sur. of Ohio. Fourth Series. Bull. I. p. 196.

[3] Ibid. p. 190.

[4] Geol. Sur. of Ohio. Vol. II, p. 483.

this vicinity within the past few years, but the mines soon cave in and are abandoned. In the extreme northeastern corner of the township, on Crooked Run, Andrews found the seam 2 feet 8 inches thick.[1] Near Whipple along the southern line of the township the coal is partly cannel, and measures about 3 feet in thickness. It is mined in a small way near that village.

Obviously all that can be expected from the Pittsburg seam in Salem township is a supply for the residents, and that can be secured only at the expense of much labor.

Fearing Township. The Pittsburg coal outcrops in the northern part of this township along Duck Creek and Whipple Run. Near Whipple, as already stated, it measures about 3 feet in thickness, and has been mined to a small extent. According to Andrews the coal dips beneath the channel of Duck Creek on the Flanders farm, approximately three-quarters of a mile below Whipple.

Liberty Township. The Pittsburg coal was seen at two places in this township. It is reported to have been stripped in the bed of Paw-paw Creek in the southwest corner of section 33, and also in the bed of the creek at Fifteen P. O. in the northern part of section 7. The coal at this place is 700 feet above sea level. Practically the entire township is underlain with this seam, but it is thin and of little importance.

Ludlow Township. The Pittsburg coal is of even less importance in this township than in the one to the west, i. e., Liberty. No places were found where the coal is at present mined, or has been mined in recent years. Along Wingett's Run, near the western border of the township, Andrews reports the seam 2 feet 10 inches thick,[2] and the interval between this coal and the Meigs Creek, 94 feet. The coal lies at the level of the flood plain of the Little Muskingum River at Flint's Mills in section 22. The coal could not be measured, but Andrews reports it only 1 foot 2 inches in thickness. Farther east in this township the seam is below drainage. Obviously the Pittsburg coal can not become an important source of fuel in this territory.

Lawrence Township. No place was found in this township where the Pittsburg coal is of workable thickness. Usually it is represented by a black streak only and sometimes even that is wanting. The seam is above drainage along Cow Run, near the postoffice, but its thickness does not permit mining.

Newport Township. The horizon of the Pittsburg coal is elevated above drainage level by the great Burning Springs anticline which crosses the Ohio River about one mile west from Newport, but the seam is not of workable thickness.

From the center of this anticline or arch the seam dips both east and west, soon disappearing below the level of the Ohio River.

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[1] Ibid. p. 485.

[2] Ibid. pp. 506-7.

THE PITTSBURG COAL IN MORGAN COUNTY.

I. East of the Muskingum River.

The Pittsburg coal is nowhere of importance in this area. It is at its best in Meigsville township where it ranges ordinarily from 15 to 24 inches in thickness. In places in this township two thin seams are found below the Meigs Creek coal, one 55 feet below this seam and varying from 12 to 20 inches in thickness; and the other about 80 feet below the Meigs Creek, and about 20 inches in thickness. The lower is the Pittsburg seam.[1] The higher of these two coals is the equivalent of the Redstone of Western Pennsylvania and the Pomeroy of Southern Ohio.

This coal is seen in the northwest corner of Meigsville township on Four Mile Run, where it measures 15 inches in thickness and lies 55 feet below the Meigs Creek coal. Three miles farther down this stream the Pittsburg coal is mined on land of C. C. Brown, and is reported to vary from 2 feet to 2 feet 6 inches in thickness. Its position here is approximately 80 feet below the Meigs Creek coal. On Dye's Fork of Meigs Creek, in the extreme northeast corner of this township, the Pittsburg seam measures about 2 feet in thickness and lies about 70 feet below the Meigs Creek.

In the southern and southeastern parts of Bristol township the Pittsburg coal measures only 18 inches in thickness, and is still thinner in the central and northern parts of the township. It is nowhere mined, and can never be a fuel of importance.

The seam is found also in southern Bloom township to the west of Bristol, where it is represented by 18 inches of coal and black shale. Elsewhere in this township the seam appears to be wanting.

The seam is occasionally noted in Malta township where its thickness corresponds with that in the other townships already mentioned.

Obviously this coal in the eastern part of Morgan county can never be of importance. It is little more than a shadow of the great seam found in Belmont and other counties.

II. The Pittsburg Coal West of the Muskingum River.

The Pittsburg coal, as a workable seam, in this part of Morgan county is limited to the two townships, Homer and Marion.

Homer Township. This township contains a larger quantity of the Pittsburg coal (here known as the Federal Creek) than is found in any other township in Morgan county. However, the coal lies high in the hills and hence is beneath only a fraction of the township. Further the coal is very unsteady in thickness, the result being that at least half

[1] Geol. Sur. of Ohio, Vol. V, p. 1066.

of the area cannot be worked. However, the coal has been mined on many farms and is an important local source of fuel.

The coal is at its best in the southeastern corner of the township where it is of workable thickness on both sides of Sharp's Fork. On the east bank of this stream the coal thins rapidly northward and has no value north of section 3. On the west bank the coal is more persistent and is workable as far north as the middle of the township, or nearly to the village Mountville.

Between Mountville and Bishopville the coal is found in good thickness on the ridges lying between Miners Fork and its western tributaries, these outliners being the remnants that have escaped stream erosion.

The coal has the structural features that are found farther south and southwest in Athens, Meigs and Gallia counties.

Section of the coal in the North Bank, southern part of section 1, near the Morgan-Athens county line:

	Ft.	In.
Bone coal	0	3
Soapstone	1	2
Coal	0	3
Pyrites streak	0	¼-½
Coal	0	7
Black streak	0	½
Coal	2	4½

Fire clay, unmeasured.

In the entry to this bank the Top coal is not present, but it is found in another opening nearby and about 200 feet from the entrance. This illustrates very well the uncertain nature of the seam.

Section 22 was measured in the Waymer Bank, on the west side of Sharp's Fork in section 2, near Joy. Altitude of coal, 837 feet.

Chemical analysis and calorific value of Section 22:

Ultimate.		*Proximate.*	
Carbon	67.39	Moisture	6.87(a)(b)
Hydrogen	5.32	Volatile Matter	40.55
Oxygen	13.98	Fixed carbon	44.39
Nitrogen	0.90	Ash	8.19
Sulphur	4.22		
Ash	8.19		
	100.00		100.00

Calorific value ..... 6,722 calories.

(a) Sample slightly wet. Moisture possibly 1% high on this account.
(b) Moisture in the air-dried sample about 3%.

The sample included the entire section except parts 1 and 3 and the bone coal comprising the base of part 4. The sample measured 6 by 1½ inches.

SECTION 22

		Ft.	In.
4. Upper bench,	Coal,	1	6
	Bone coal,	0	8
3. Soapstone,		0	11
2. Lower bench,	Coal,	0	2
	Parting,	0	⅛
	Coal,	0	7½
	Parting,	0	½
	Coal,	0	3
	Parting,	0	⅜
	Coal,	0	1½
	Parting,	0	⅜
	Coal,	2	0
1. Clay, unmeasured,			

Northward the coal thins rapidly, and in the northern part of section 3 is thin or wanting.

The Ames limestone is prominent in this locality, the interval between it and the coal being 170 feet. A short distance below Joy the limestone disappears beneath the valley.

Farther north along this stream the coal continues with both benches and is worked on the Berry farm in section 9. Northward it thins rapidly, soon losing its commercial value.

The following section was measured in the Lewis bank in the southeastern corner of section 15, near the center of the township.

	Ft.	In.
Soapstone	1	1
Coal	1	½
Shale parting, thin	0	0
Coal	2	11

Here the lower bench only is present. Southward the coal thins rapidly, and in a few hundred yards is not workable. In the Hogsett bank near the eastern margin of this section, however, both benches of the coal are found in good thickness.

The following measurement was made in the Steffy Bank in section 29 along the extreme western margin of this coal:[1]

[1] Geol. Sur. of Ohio. Vol. VI, p. 652.

		Ft.	In.
Upper bench	Coal	1	8
	Shale parting		
	Coal	2	0
Clay		1	0
Lower bench	Coal	0	4
	Shale parting		
	Coal	1	0
	Shale parting		
	Coal	1	11
	Shale parting		
	Coal	0	8

Marion Township. In this township the Pittsburg coal is of value in the southwestern corner only. The best deposits are found along Sharp's Fork and Opossum Run in sections 31 and 19. Probably the area of workable coal does not exceed four square miles. The coal is due in the northern part of the township, but is there represented by a black streak or is entirely wanting.

The following section of the coal was measured in the Edgerton Bank on Opossum Run near the Morgan-Athens county line:

		Ft.	In.
Shales, unmeasured.			
Upper bench	Coal	2	6
	Bone coal	1	0
	Coal	0	4
Soapstone		1	0
Lower bench.	Coal	3	7

In this mine the Upper bench is uneven and contains boulders of sandstone with pyrites. For this reason the bench is little used. The mine is worked throughout the year, supplying the neighboring farmers with fuel. Southward the Upper bench thickens and is important, but farther north along Opossum Run it is valueless.

THE PITTSBURG COAL IN ATHENS COUNTY.

The Pittsburg coal, here called the Federal Creek, is well developed in two townships, Ames and Berne and especially in the latter. It is found also in at least a half dozen other townships, but in them is of relatively small importance.

Here the structure of the seam forms a marked contrast with that found along the Ohio River in Belmont and Jefferson counties. The well known divisions such as Breast coal, Brick coal, etc., are wanting and the seam is divided into an Upper and Lower bench by a bed of clay or shale of varying thickness. From a study of the coal in this and in Gallia county and in the western part of Belmont it appears that the bed of shale or clay corresponds to the Bearing in coal with the

partings above and below, while the coal below the parting in question represents the Brick and Bottom coals, and the coal above the parting the Breast coal.

The thickness of the seam is much less uniform than farther east in the state and the coal is inferior in composition. Nevertheless it constitutes an important source of fuel, and in years to come will be better appreciated than at present.

Berne Township. The Pittsburg or Federal Creek coal is an important seam in this township. It outcrops in the valley of Federal Creek and its principal tributaries, Sharp's Fork, Opossum Run and Marietta Run. Probably the seam has been more extensively mined here than in any other township in Southern Ohio, and the production would be much greater if the shipping facilities were adequate.

At two places, Utley and Lathrop, the coal has been coked. On Federal Creek, just below Utley 125 ovens were built, but probably not more than 50 of these were in use at any one time. The coke is said to have found a ready market in Cleveland, Toledo, Chicago, Cincinnati and other places. Slack coal was used, the lump being thought too valuable for this purpose. Hence two kinds of cars were needed, one for coke and another for coal. The cars for coke are reported to have been secured without difficulty, but the supply for coal was insufficient and in consequence the works were closed about 1896. A few years later an attempt was made to reopen the coal mine, but the old difficulty again prevented success. This mine has employed 75 men and perhaps 15 more about the coke ovens. Mining was done by machinery, compressed air being the power.

The coke ovens at Lathrop number 50, but have not been used for years. However, they were being repaired during the summer of 1907 and probably by this time coke is being made. These ovens are the property of the Black Diamond Coal & Coke Company. The mine of this company was opened about 20 years ago, and during that time has been much hampered by a dearth of cars for shipment. Electric power is used, the mining being done by machinery. Section 23 was taken in this mine.

Chemical analysis and calorific value of Section 23:

Ultimate.		*Proximate.*	
Carbon	67.55	Moisture	5.78(a)
Hydrogen	5.14	Volatile Matter	37.43
Oxygen	14.17	Fixed carbon	48.79
Nitrogen	0.95	Ash	8.00
Sulphur	4.19		
Ash	8.00		
	100.00		100.00

Calorific value ..... 6,833 calories.

(a) Moisture in the air-dried sample about 3%.

PLATE II. Abandoned Coke Ovens and Coal Tipple at Utley, Athens Co.

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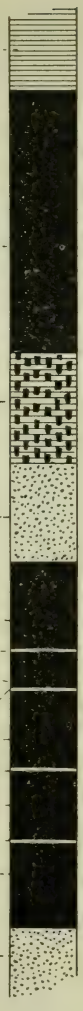
SECTION 22

		Ft.	In.
5. Shale, unmeasured,			
4. Upper bench.	Coal,	2	7
	Bone coal,	1	1
3. Soapstone,		1	0
2. Lower bench.	Coal,	0	10
	Parting,	0	⅜
	Coal,	0	4
	Parting,	0	¼
	Coal,	0	9
	Parting,	0	¼
	Coal,	0	8
	Parting,	0	¼
	Coal,	0	10
1. Clay, unmeasured,			



This sample included everything shown in the section except parts 1, 3 and 5 and the lower part (Bone coal) of 4. The sample measured 5½ by 1 inch.

Prominent in this mine and in other mines in this general locality are numerous "boulders." These are masses of sandstone or sandstone and pyrites, and vary much in size and shape. The largest may weigh a ton or more while the smallest are the size of pebbles. Sometimes the "boulders" are round, but more frequently they are decidedly oval. Not uncommonly they are nearly flat.

Generally the "boulders" are not found in equal abundance in all parts of the seam, and in the mine just described are rare in the Lower bench. Obviously the "boulders" are objectionable, since they diminish the quantity of coal and their handling is a dead loss.

The draw slate is uniform in thickness and except in being less of a shale and more of a clay, corresponds very well to the same formation in Belmont and adjoining counties.

Below is a section in the Schuler mine at Sharpsburg:

		Ft.	In.
Shale, unmeasured.			
Upper bench	Coal	4	0
	Bone coal	0	2
	Coal	0	4
Draw slate (clay)		1	0
Lower bench	Coal	2	10
	Pyrite streak	0	½
	Coal	0	8
Fire clay, unmeasured.			

The Upper bench here contains numerous "boulders" while the Lower bench is quite free from them. However, the Lower bench frequently contains thin shale or clay partings.

The coal is undercut by machines, but in other respects the methods are not so progressive. Ordinarily the miners number from 10 to 30, and shipment is entirely by rail. In other words this mine does not supply a local trade.

Lying about 25 feet above the coal is a thin stratum of limestone, and still higher a massive ledge of sandstone. The latter is prominent in this territory and appears to be the equivalent of the Pomeroy sandstone. The Pomeroy coal, however, which is due under the sandstone, was not found. It appears to be wholly absent in this part of Ohio.

In section 13 the limestone occurring 60 to 70 feet above the Pittsburg coal is more or less replaced by a sandstone containing large masses of white limestone which gives the rock a peculiar mottled appearance.

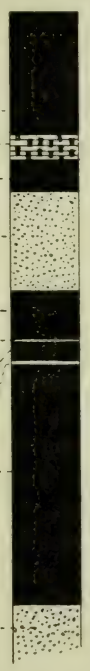
The following section, measured near the center of section 24, shows the strata from the Pittsburg coal up:

	Ft.	In.
Sandstone, slightly conglomeritic, weathers brown	38	0
Shales, red and gray	4	0
Shales, sandy	5	6
Clay, red	5	0
Sandstone, thin bedded	23	0
Clay, red with limestone nodules	17	6
Shale	20	6
Limestone and clay	8	0
Shale, dark	1	0
Limestone with interbedded clay	20	0
Not well shown, much limestone	11	0
Limestone, yellow, honeycombed	8	0
Sandstone, shaly	8	0
Shale, black streak		
Limestone interbedded with clay	60	0
Sandstone, Pomeroy	16	0
Shale	17	0
Coal, Pittsburg	8	0

The third important mine is at Broadwell in the southeastern part of the township, and is operated by the Federal Coal Company of Marietta, Ohio. Section 24 was taken in this mine.

SECTION 24

		Ft.	In.
4. Upper bench,	Coal,	1	3
	Bone coal,	0	3¼
	Coal,	0	4
3. Soapstone,		1	0
2. Lower bench,	Coal,	0	6
	Parting,		
	Coal,	0	2
	Parting,	0	¼
	Coal,	2	5
1. Clay, unmeasured,			



Some pyrites nodules are found in the coal, especially in the Lower bench. Where normal the roof is shale, even and strong. Often, however, the roof is irregular and composed of hard clay or shale, with smooth slickenside like surfaces.

Chemical analysis and calorific value of Section 24:

Ultimate.		*Proximate.*	
Carbon	66.61	Moisture	6.60(a)
Hydrogen	5.13	Volatile Matter	35.05
Oxygen	13.72	Fixed carbon	48.15
Nitrogen	0.93	Ash	10.20
Sulphur	3.41		
Ash	10.20		
	100.00		100.00

Calorific value ..... 6,607 calories.

(a) Moisture in the air-dried sample about 3%.

In this sample part 2 only of the section is included. The sample measured 6 by 1½ inches and was cut from a fresh surface in a dry room.

Part 4 of the section was sampled separately. In this sample the

Bone coal was rejected, as it is also by the miners. This sample was wrapped in the sampling cloth and one hour and a half later was put in a can and sealed in the usual manner. Below is the analysis of this part of the seam:

Ultimate.		*Proximate.*	
Carbon	65.92	Moisture	4.51(a)
Hydrogen	5.10	Volatile Matter	38.24
Oxygen	11.62	Fixed carbon	45.76
Nitrogen	0.99	Ash	11.49
Sulphur	4.88		
Ash	11.49		
	100.00		100.00

Calorific value ..... 6,636 calories.

(a) Moisture in the air-dried sample about 3%.

The coal is cut by machines but is hauled by mules and cable.

Other mines exist in the vicinity of Broadwell, especially along Marietta Run. One of these, the Grandstaff, supplies a large local demand among the farmers. Formerly there was a mine at Big Run but this has been abandoned several years because of inadequate shipping facilities.

From Broadwell the coal may be followed south into Rome township where it goes under cover in section 19.

It is doubtful if the coal in good thickness extends in the hills far west of Broadwell. No mines are in operation on the west bank of Federal Creek above Broadwell, and the Upper bench of the coal is reported to be absent in most places in that locality. The township line just east of Amesville is regarded as the extreme western limit of workable coal on the south bank of Federal Creek.

Ames Township. The Pittsburg or Federal Creek coal is an important local source of fuel in this township. No shipments are made by rail. The coal is at its best in the northeastern part of the township between Linscott Run and Hyde Fork, but even there, as the sections given below show, the seam is inferior in thickness to the coal in Berne township. The coal west and southwest of this territory is thin and sometimes absent.

Section of coal measured in the Jones bank, southwest corner of section 5:

		Ft.	In.
Shales, unmeasured.			
Upper bench	Coal	0	1
	Shale, dark	0	3
Draw slate, (clay)		1	0
Lower bench. Coal		3	6

This shows the Upper bench marked by a streak of coal. Sometimes this increases in thickness several inches, but does not become workable.

In the southeastern part of this section the coal measures less than 36 inches, but along Linscott Run, farther north, the coal improves. Thus in the Moses Ball mine in section 6 the Lower bench has 46 inches of coal, though the Upper bench measures only 4½ inches of good coal; but farther around the hill the Upper bench is present in full and the total thickness of the seam is there reported to be 8 feet.

The coal was found as follows in the Rice bank, section 11:[1]

	Ft.	In.
Coal	0	5
Clay	1	0
Coal	0	8
Shale streak	0	0
Coal	2	0
Shale streak	0	0
Coal	0	8

The interval between the Ames limestone and the Pittsburg coal in this section is only 125 feet, as shown by the aneroid barometer. This is less than at Joy, a few miles farther north where the interval measures 170 feet.

The following section was made near the center of section 35, along the extreme western outcrop of the Pittsburg coal:

	Ft.	In.
Clay with imbedded limestone	23	0
Shales	12	0
Pittsburg coal	1	0
Clay with imbedded limestone	13	0
Shales, sandy	20	0
Limestone	1	3

However, on the Sayres farm, in the southeast corner of section 36 the coal measures from 4 to 5 feet, and is mined for home use. Farther north in sections 30 and 36 the coal is also of workable thickness.

In section 23 the Meigs Creek coal is frequently seen. Its position is about 110 feet above the Pittsburg coal, which is from 20 to 30 feet greater than the corresponding interval to the northeast in Belmont county. On the Kasler farm the coal has been mined and is reported to be from 36 to 40 inches thick. Numerous other openings in the Meigs Creek coal have been made in this section, but no mine is now worked.

From what has been said it is clear that the Pittsburg coal in this township is very uncertain and of value in places only.

Athens Township. The Pittsburg, or No. 8, coal is limited to the tops of the highest hills in the eastern part of this township. Probably the workable coal does not exceed a few acres in area.

The following section was measured with an aneroid barometer on a

[1] Geol. Sur. of Ohio, Vol. VI, p. 651.

hill one mile southeast of Athens. It shows very well the various strata and gives approximately at least their thickness:

	Ft.	In.
Shaly sandstone, unmeasured		
Coal blossom, Pomeroy, No. 8a		
Limestone nodules and shales	20	0
Coal blossom, Pittsburg, No. 8		
Shales	5	0
Sandstone	35	0
Coal blossom		
White limestone	2	0
Shales	57	0
Bastard limestone	1	0
Shales	43	0
Ames limestone	1	8
Unseen, mostly shales	85	0
Cambridge limestone	2	0
Shales, unmeasured.		

The white limestone with the coal blossom above, is common in the southern part of Athens county. The coal blossom has a more extensive range, being common in Meigs county, but the limestone is there wanting. The coal is rarely more than 15 inches thick and is very slaty.

The Cambridge limestone is well shown along the Baltimore & Ohio railroad tracks in Athens, while the Ames limestone is found higher in the hill.

At Athens the shale near the horizon of the Ames limestone is utilized for the manufacture of brick by the Athens Brick Company. The following section was made in this pit:

	Ft.	In.
Sandstone	5	0
Shales	30	0
Ames limestone	1	4
Shales, blue and red	35	0

The Middle Kittanning coal is shafted on Sugar Creek in the northeastern part of the township, by the Sunday Creek Coal Company.

In section 1 near the head of the Middle Branch of Shade River, the shales overlying the Pittsburg coal contain much silicified wood, and many fine museum specimens have been taken from this locality.

Canaan Township. This township, which lies south of Ames, probably contains even less of the Pittsburg coal than does the latter. In fact throughout the greater part of this township the coal in question is entirely wanting or is represented by a black streak only. The workable coal is confined to a narrow strip about one mile wide extending across the southwestern corner of the township, with an outcrop along the valley of Long Run and the hills facing the Hocking River.

On the north side of the Hocking River the total area of workable coal is probably less than 500 acres lying in sections 34 and 35. The

coal farther north is reported to be less than 24 inches thick. To the east the coal thins rapidly and in places is represented by only a streak of clay. South of the Hocking River a trace of the Pomeroy or 8a coal lying about 20 feet above the Pittsburg is occasionally found.

Near the north edge of section 34 on the Mansfield farm much coal has been mined in former years. Both benches are reported with a total thickness of about 6 feet. The altitude of the coal here is 871 feet. The following section was taken on the same farm with an aneroid barometer:

	Ft.	In.
Shale, unmeasured.		
Coal Pittsburg No. 8	6	0
Unseen	12	0
Sandstone	50	0
Unseen	106	0
Ames limestone	1	6

The coal is said to be nearly worked out in section 33. In the Finsterwald bank the structure is as follows:[1]

		Ft.	In.
Upper bench	Coal	0	7
	Slate streak		
	Coal	2	1
	Bone coal	0	7
	Coal	0	5
Draw slate (clay)		0	10
Lower bench	Coal	0	6
	Slate streak		
	Coal	2	6

The following section was taken on the Sheridan farm in the northwest corner of section 25, where the coal has been stripped for the local market:

		Ft.	In.
Shale, unmeasured.			
Upper bench	Coal	2	2
	Bone coal	1	0
Draw slate		1	7
Lower bench	Coal	0	4
	Shale	0	¼
	Coal	0	5
	Shale	0	¼
	Coal	0	7
	Shale	0	1
	Coal	2	1
	Shale	0	10
Clay with limestone nodules		15	0
Sandstone		40+	

[1] Geol. Sur. of Ohio, Vol. VI, pp. 646-647.

The top coal is very irregular and contains many lenticular "boulders."

On the west side of Long Run the Upper bench of the coal is usually wanting and the Lower bench is often below the normal thickness.

At the head of Willow Creek near the Eastern margin of section 25 the coal is reported to be 30 inches thick. Farther east the coal thins rapidly.

The limestone ledge, the base of which lies about 65 feet above the Pittsburg coal, is persistent throughout the township and forms conspicuous bluffs in many places along the Hocking River. The slaty coal above the limestone is usually present.

The sandstone, the base of which is about 90 feet above the Ames limestone, attains an unusual thickness in the western part of the township, often extending up close to the Pittsburg coal. This sandstone is quite prominent in sections 28 and 34.

In the northwest corner of section 9 the Middle Kittanning coal is reached by a shaft recently put down by The Canaan Coal Company.

Rome Township. The Pittsburg coal horizon has been exposed by stream erosion in only three sections in this township, namely, 32, 33 and 18. Near the southeastern edge of section 32 the coal dips beneath the bed of Hocking River. In this territory the coal is represented by a dark streak only.

The Pittsburg coal rises above drainage on Federal Creek in section 18 near the mouth of Big Run. Here the coal was formerly mined.

At Kilvert, near the north edge of section 17 the coal has been mined by shafting, the depth being 40 feet.

The Meigs Creek coal is mined in several places along Big Run. The following section was taken in the A. V. Duffy bank near the west edge of section 6:

	Ft.	In.
Coal	2	1
Shale	1	8
Coal	0	5

The Federal Creek, or No. 8, coal has been reached by a shaft sunk by the Arcadia Coal Company on Two-mile Run near the southern edge of section 4, Decatur township, Washington county. The shaft has a depth of 117 feet and was sunk about the year 1897. A good thickness of coal is said to have been found, but the plant has long been quiet. The altitude of the coal there is 513 feet. At Sharpsburg 8½ miles north, 20 degrees west, the Pittsburg coal has an altitude of 741 feet. Hence the dip per mile, between the two points in question is 27.8 feet.

The base of the following section, taken near the center of section 32, is about 65 feet above the Pittsburg coal horizon:

	Ft.	In.
Sandstone, thin bedded	15	0
Shale	5	0
Slaty coal	0	8
White limestone, interbedded with clay	30	0
Black streak	0	½
Clay with limestone nodules	5	0

The limestone ledge of the above section dips below the bed of the Hocking River near Stewart Station.

On Green Run near the township line south of Guysville, the coal above the limestone has been stripped, a thickness of from 8 to 15 inches being reported.

Alexander Township. The Pittsburg coal is very uncertain in this township. There is doubtless some workable coal in nearly every section where it outcrops but the thickness varies much and rapidly. In the northeastern corner of the township, in sections 5, 6 and 12, the coal is represented only by a black streak. In sections 10 and 11 considerable coal has been taken out in former years.

The Pittsburg coal is mined in the Bennet bank, northeast corner section 4, to supply the country market. The following section of the coal was furnished by a miner. It represents the Lower bench only, the Upper bench being absent.

	Ft.	In.
Shale, unmeasured.		
Soapstone	1	0
Coal	1	6
Shale	0	½-1
Coal	1	6
Pyrites	0	½-1
Coal	1	3
Fire clay, unmeasured.		

Several inches of coal are left in the roof to support the soapstone.

In the southeastern part of the township the coal is usually thin and has been worked in very few places. Considerable coal has been taken out in the high ridges of sections 9, 14, 15, 20 and 21.

The following section was taken on the road near the Bennet mine:

	Ft.	In.
Shale, unmeasured.		
Pomeroy coal, No. 8a	1	0
Shale with nodular limestone	21	6
Pittsburg coal No. 8	4	0
Shale	8	0
Sandstone, unmeasured.		

In section 26 the aneroid showed the interval between the Pittsburg coal and the Ames limestone to be 164 feet.

Lodi Township. It is probable that the Pittsburg coal is present in workable quantity over two-thirds of Lodi township. However, the Pittsburg horizon has been cut through only along the deeper valleys and hence the extent of the out-crop is rather limited. The seam is shown along the following streams: Willow Creek, sections 12 and 18; the Middle Branch of Shade River extending diagonally southeast across the township; Long Run, sections 19, 25, 26, 32 and 33.

On Willow Creek, near the northern edge of the township, the Pittsburg coal is wanting.

Along the Middle Branch of Shade River the Pittsburg, or No. 8, coal is workable from the southeast corner of section 29 to where it dips below the bed of the creek in the northwest corner of section 9.

At Judson P. O. section 17, the coal has been mined in a small way for many years, a thickness of four feet being reported. The altitude of the coal is 725 feet, and it is very near the level of the flood plain of Shade Creek. Farther down stream, the coal has been stripped in various places. Along this stream the coal is for the most part restricted to the Lower bench.

In describing Athens township mention was made (p 78) of a coal blossom, overlain by massive sandstone, which lies about 90 feet above the Ames limestone. In the southwest corner of section 36, Lodi township, this coal attains a thickness of 30 inches and has been mined on the Rogers farm. The altitude of the seam is there 755 feet. This seam is rarely more than a shale streak and has not been observed in workable quantity at any other place.

The structure of the Pittsburg coal in the Fulton bank on the eastern side of Long Run, section 30, is as follows:

		Ft.	In.
Shale, unmeasured.			
Upper bench	Coal	2	4
	Black slate	1	0
	Coal	0	4
Soapstone		1	0
Lower bench, Coal		2	4
Fire clay, unmeasured.			

The structure of the coal here is very similar to that of the Federal Creek region. Both benches are mined and the shale roof is strong.

Dover Township. The eastern part of this township contains numerous unusually high hills, some of which reach the horizon of the Pittsburg coal. However, the workable coal is limited to three small hills in the eastern part of section 6, where the seam attains a thickness of 4 feet.

The coal is due in the high ridges in sections 3, 4 and 9 but scarcely a black streak can be found. In section 9 a slaty coal, commonly occurring about 90 feet above the Ames limestone, has a thickness of over

5 feet, while about 50 yards away not even a black streak can be seen although the rocks are well exposed.

The massive sandstone immediately above this stratum is unusually thick, reaching up to the Pittsburg horizon.

Trimble Township. Sections 1 and 2 of this township contain a few hill tops where the Pittsburg coal is due but the seam is wanting.

The following section was taken at Tunnel No. 3, on the M. C. & C. R. R.:

	Ft.	In.
Sandstone, unmeasured.		
Shales	7	0
Shales, dark	8	0
Ames limestone	0	2
Black shales	3	10
Coal	1	0
Clay with nodular limestone	8	0
Shales, sandy	3	0
Sandstone	6	0

The coal is often thicker than shown in the above section and has been stripped by the farmers in many places.

THE PITTSBURG COAL IN MEIGS COUNTY.

The seam is important in two townships only in this county, namely, Scipio and Bedford. In these the coal is inconstant and at its best only a local source of fuel. The Upper bench is of little or no value and sometimes entirely wanting. To the south the coal thins and along the Ohio River is wholly wanting.

Bedford Township. The greater portion of this township holds the Pittsburg coal with a moderate thickness. The seam is locally termed the "Four Foot Vein," but more often has a thickness of 3 feet. It outcrops along Kingsbury Creek and the West Branch of Shade River. "Boulders" are characteristic of the fuel, and farmers will go many miles to get the Pomeroy or 8a coal for domestic purposes rather than use this seam.

The Pomeroy or 8a coal is everywhere present, from 15 to 25 feet above the Pittsburg, or No. 8, seam.

The streams in the eastern portion of the township often have narrow gorge like valleys, doubtless due to the resistance to erosion of the massive sandstone above.

The following section was taken near the eastern edge of section 20, where the Pittsburg coal dips below the bed of Kingsbury Creek:

	Ft.	In.
Sandstone, over 4 feet.		
Shales	2	0
Pomeroy coal, No. 8a	1	6

	Ft.	In.
Shales, blue	8	0
Shales with nodular limestone	11	0
Shaly sandstone	9	0
Pittsburg coal, No. 8	2	6+

The Pittsburg coal is extensively stripped in the southeast corner of section 15 on the land of H. Riggs, to supply the country demand.

A section of the coal is as follows:

		Ft.	In.
Shales, dark, unmeasured.			
Upper bench.	Coal	0	3
Soapstone		1	3
Lower bench	Coal	1	0
	Shales	0	1
	Coal	1	0
	Shales	0	1
	Coal	1	6

In section 9 a short distance east of this point the Pittsburg coal dips below the bed of the West Branch of Shade River.

In the Haning bank near the south edge of section 36, the coal is as follows:

	Ft.	In.
Shales, unmeasured.		
Coal	1	2
Clay streak		
Coal	1	10
Clay	0	½
Coal	0	11
Fire clay, unmeasured.		

Here the Lower bench of the seam only is present.

On the west side of Shade Creek the coal is usually thinner and the Upper bench entirely wanting. On the land of J. Bobo, northwest corner section 23, the following measurement was made by means of the hand level:

	Ft.	In.
Sandstone, unmeasured.		
Shales	10	0
Pomeroy coal, No. 8a	1	4
Shales	21	0
Pittsburg coal, No. 8	4	0
Clay containing limestone nodules	4	0

In the southern part of the township along Pratts' Fork, the Pittsburg coal is usually limited to the Lower bench and is known locally as the "Four-Foot Vein." The soapstone above the Lower bench does not make a good roof and therefore several inches of coal are left up to support the soapstone.

Near the eastern edge of section 25, the coal has been mined in the Sapps bank for the local market. The Lower bench only is found. It shows the following structure:

	Ft.	In.
Soapstone, unmeasured.		
Coal	1	0
Pyrites	0	½
Coal	1	8
Pyrites	0	1
Coal	1	0
Shales, unmeasured.		

The following section was taken at the entrance of the Williams bank in the northwest corner of section 19. As will be noted the Lower bench only of the coal is present.

		Ft.	In.
Dark shales, unmeasured.			
Shales		0	10
Lower bench	Coal	0	7
	Shale parting		
	Coal	1	4
	Shale parting		
	Coal	2	0
Dark shales		3	9
Limestone, impure		2	4
Shales, calcareous		3	0
Sandstone in bed of stream.			

The thickness of the coal in the mine is usually greater than shown in the section.

In this region the coal very often contains the pyrites—sandstone "boulders" so common in the Federal Creek region. They range from 2 to 10 feet in diameter and are so abundant that it is difficult to get miners to work the coal.

The downstream limit of the outcrop of the Pittsburg coal on Pratts' Fork is near the eastern edge of section 19.

Scipio Township. About one-half of this township is underlain with the Pittsburg coal, but the thickness is very changeable and uncertain. In the southern half of the township the seam is of little value, the Pomeroy coal being the seam worked in that locality. In the northern half of the township the Pittsburg coal ranges from 2 to 4 feet in thickness and contains much pyrites, hence the coal is not very desirable for domestic purposes.

The Ames limestone rises above drainage about the middle of the township. In this locality it consists of fossiliferous limestone nodules imbedded in shales. The following section was taken with an aneroid oa the road a short distance west of Downington postoffice:

	Ft.	In.
Sandstone, unmeasured.		
Coal, Pomeroy, No. 8a	1	8
Calcareous shales	15	0
Coal, Pittsburg, No. 8	3	0
Shales	15	0
Massive sandstone	40	0
Shaly coal	0	4
Shales, red and gray	60	0
Red clay with nodular iron ore	20	0
Shales, gray	10	0
Ames limestone, nodular and imbedded in shales	15	0

Eastward from Downington Postoffice the Pittsburg coal gradually thickens, reaching nearly 4 feet in the eastern part of the township.

In the southeast corner of section 17 the Pittsburg coal is mined in the Suddeth bank. The structure of the coal is as follows:

	Ft.	In.
Clay, unmeasured.		
Coal	0	3
Clay streak		
Coal	1	6
Pyrites streak	0	¼
Coal	0	9
Clay, unmeasured.		

This represents the Lower bench only, the Upper bench being absent.

In the southern part of the township a ledge of white limestone, about 10 inches thick, occurs 30 feet above the Ames limestone.

THE PITTSBURG COAL IN GALLIA COUNTY.

This seam is important in this county and is known locally as the Swan Creek, Lewis or Jeffers coal. It is of value in Ohio, Guyan, Clay, Harrison and Green townships only, and in one (Ohio) is shipped by river. The seam varies much in thickness from place to place, and is very similar in structure to the same seam in Northern Athens and the adjacent part of Morgan county.

Outside of the townships named in the preceding paragraph the coal is very thin and frequently is not represented by even a streak.

In previous reports of the Survey little attention was given to this coal. Andrews correctly identified the seam lying about 50 feet higher as the Pomeroy which he regarded as the Pittsburg, but the seam in question he did not classify.[1] Its structure and position with reference to the underlying Ames limestone and the overlying Pomeroy seam leaves no doubt as to its being the Pittsburg coal.

[1] Geol. Sur. of Ohio, Vol. I, pp. 225-246.

Ohio Township. This is one of the smallest townships in the county, but it contains considerable coal. The Pittsburg coal outcrops along the Ohio River and also along Swan Creek to the northern line of the township. Likewise the seam outcrops in the valley of Little Swan Creek. These valleys are narrow and hence the quantity of coal cut out is small.

While the Pittsburg coal underlies the whole of this township except where removed in valleys, it varies greatly from place to place. The areas where the coal has been demonstrated to be thick and important are small and confined to a strip just below Bladen along the Ohio River and to another small area along Swan Creek, almost due west of Bladen.

In the southeastern part of the township the coal appears to be very thin, perhaps entirely wanting, and the same is probably true along the extreme southern part of the township.

The coal is everywhere due along Little Swan Creek, and has been stripped in the bed of this stream in section 4. No banks have been opened, however, and the coal promises little in this locality.

The best known mine in the township is the "Klondyke," owned by the Swan Creek Coal Company of Gallipolis. The mine is located on the Ohio River a short distance below Bladen, and has been in operation about ten years. About 20 miners are employed except when the river is blocked by ice or the water is extremely low. Shipment is by river, and principally to Cincinnati. Section 25 was measured in this mine, the entrance to which is 570 feet above sea level.

Chemical analysis and calorific value of Section 25:

Ultimate.		*Proximate.*	
Carbon	64.94	Moisture	5.80(a)
Hydrogen	5.16	Volatile Matter	36.76
Oxygen	14.40	Fixed carbon	47.38
Nitrogen	1.10	Ash	10.06
Sulphur	4.34		
Ash	10.06		
	100.00		100.00

Calorific value .....6,551 calories(b).

(a) Moisture in the air-dried sample about 3%.

(b) The ultimate analysis and calorific value here given were not obtained until several weeks after the preparation of the fine sample, and laboratory experiments indicate that the sample had increased in weight by oxidation about 1½%. A calorific value about 100 calories higher than that given appears to more nearly represent the fresh sample.

The sample included parts 2 and 4 of the section, and was 10 inches wide and 2 inches deep.

The Upper bench is thin and unimportant, sometimes absent. Much the same is true of the soapstone below. According to the miners the latter rarely exceeds 12 inches and occasionally is wanting. About two

SECTION 25

	Ft.	In.
6. Massive sandstone,		
5. Shale, reported,	2	6
4. Upper bench, Coal,	0	4½
3. Soapstone,	1	0
2. Lower bench, Coal,	2	9
1. Clay, unmeasured,		

feet above the bottom of the seam a fairly persistent thin band of pyrites was found, and occasionally a streak of bone coal.

The Lower bench is not undercut but shot on the solid. Next the soapstone is pulled down and finally the Upper bench or top coal is removed.

The shales overlying the coal are reported to vary in thickness from one to fourteen feet. Above these is a massive sandstone.

North and south from this mine the coal thins rapidly, making the workable area along the river front very narrow.

Below is a section of the coal in the William Elliot mine in section 29, on the western bank of Swan Creek:

	Ft.	In.
Shales, unmeasured.		
Upper bench. Coal	0	5½
Shales	1	7
Lower bench. Coal	3	4
Shales, unmeasured.		

The shale parting separating the two benches ranges from 4 to 25 inches in thickness. The Upper bench coal varies from 5½ to 10 inches,

and the Lower bench usually from 36 to 40 inches. This mine has been in existence for perhaps 20 years, and supplies a local demand.

About 100 yards north of the Elliot bank is that of Samuel Lewis, in which the following section was measured:

		Ft.	In.
Shales, unmeasured.			
Upper bench	Coal	1	3
	Shale	0	2½
	Coal	1	6
	Coal and shale	2	7
Draw slate (clay)		0	11
Lower bench. Coal		3	0

The draw slate is reported to range from one to fifteen inches in thickness and to average 6.

This mine supplies a local trade, and has been worked for about 15 years. At the entrance of the mine the coal is 592 feet above sea level. Other mines have been opened in this vicinity.

In the extreme northwestern corner of section 30 on land of Thomas Erwin the coal is found in the bed of Swan Creek, and is reported to measure as follows:

		Ft.	In.
Upper bench	Coal	1	6
	Shale, dark	2	6
	Coal	0	6
Draw slate (clay)		0	10
Lower bench. Coal		3	2

Coal No. 8a (Pomeroy) is reported 32 feet higher and 15 inches in thickness.

Clay Township. What has been said about the Pittsburg coal in Ohio township applies very well to the same seam in Clay. However, the coal appears to be steadier in thickness in this township than in Ohio, and in consequence is more widely worked. Especially is this true south of Raccoon Creek where the coal is mined at numerous points from Yellowtown, southeast, to near Chambersburg.

North of Raccoon Creek the seam is much thinner and is rarely mined. It is the Pomeroy or 8a coal that is worked there, and this, too, is of little importance.

At Yellowtown the coal is 705 feet above sea level. It has long been mined at a number of places in this vicinity for local trade. The following section was measured in the entry of a new bank on the hill just south of the village:

	Ft.	In.
Shales, dark	4	0
Upper bench. Coal	1	0
Shales	2	0
Lower bench. Coal	2	10
Clay, unmeasured.		

The seam is or has been worked at several places east of Yellowtown, on the south bank of Raccoon Creek. However, the coal there is thin.

At the entry to the Elizabeth Dodd bank, two miles southeast of Yellowtown the following measurement was made:

	Ft.	In.
Shale, dark	4	6
Upper bench. Coal	1	0
Shales	0	10
Lower bench. Coal	3	1
Clay, unmeasured.		

The coal is at its best on Teens Run and Little Teens Run in the southeastern part of the township.

The following section was made in the Hazlett bank on Little Teens Run:

		Ft.	In.
Sandstone		12	0
Shale, light		1	6
Upper bench	Coal	2	0
	Shale, black	2	4
	Coal	0	8
Shales		0	8
Lower bench	Coal	1	8
	Pyrites band	0	1
	Coal	1	8

The band of pyrites in the Lower bench is very hard and quite persistent. This bench ranges from 3 to 3½ feet in thickness and is quite steady. The Upper bench is divided into two parts by a bed of shales of unusual thickness. The coal below the shales is fairly uniform, but that above varies much owing to the changing thickness of the shales. The Lower bench only is worked. This mine has been in operation in an irregular way for about forty years.

The 8a or Pomeroy coal is found along this run, about 27 feet above the Pittsburg seam and is reported 18 inches in thickness.

On Teens Run the coal has been opened at several places, but the best known mine is the Jeffers. The following section was furnished by Mr. Jeffers:

	Ft.	In.
Shales, black, unmeasured.		
Upper bench. Coal	1	0
Shales	1	0
Lower bench. Coal	3	0

The shales above the Lower bench were reported to vary from 3 to 24 inches in thickness. Probably the section of the Upper bench is incomplete, the coal above the black shale being omitted.

South from Teens Run the coal thins, decreasing in value until the Swan Creek field in Ohio township is reached when it again becomes

of value. While Clay township will probably never be a larger producer of coal, it nevertheless contains an ample supply for local use.

Green Township. The Pittsburg or No. 8 coal in this township appears to be restricted to sections 7 and 8, just east of Raccoon Creek. Mining is done only in section 8, and it may be that in section 7 to the south the coal is wanting. The coal is due in the high hills in the southeastern quarter of the township, but as already stated is usually absent. Section 26 was measured in the Odell bank in section 7.

SECTION 26

	Ft.	In.
7. Shale,	1	2
6. Coal,	0	7
5. Parting,	0	⅛
4. Coal,	0	11
3. Parting,	0	¾
2. Coal,	1	1
1. Clay, unmeasured,		

About 20 feet higher in the hill the Pomeroy or 8a coal is found, and is reported by Mr. Odell to be from 18 to 20 inches thick.

Chemical analysis and calorific value of Section 26:

Ultimate.		*Proximate.*	
Carbon	62.30	Moisture	6.73(a)
Hydrogen	5.11	Volatile Matter	34.34
Oxygen	14.05	Fixed carbon	45.90
Nitrogen	1.14	Ash	13.03
Sulphur	4.37		
Ash	13.03		
	100.00		100.00

Calorific value ..... 6,356 calories.

(a) Moisture in the air-dried sample about 3%.

The sample included the entire section except parts 1, 3 and 7, and was 10 inches wide and 2 inches deep.

Guyan Township. The Pittsburg or Swan Creek coal while due in the hills throughout this township, is found only in the northeast corner in sections 11, 12 and 18. Elsewhere in the township the seam is wanting or is represented by a streak only.

Near the village Mercerville two seams are or have been worked. These are shown on or near the Robinson farm just north of the village. The lowest of these seams is the Pittsburg or No. 8. In the entry of an old bank the following measurement of this coal was made:

	Ft.	In.
Shale, unmeasured.		
Rotten coal	0	6
Shale	3	0
Coal. Upper bench	1	0
Soapstone	0	10
Coal. Lower bench	2	8

A few hundred feet southeast of this locality is a small bank where a little mining has been done. In the entry of this bank the section was as follows:

	Ft.	In.
Shales, thickness exposed	6	0
Coal	1	10

This coal is 51 feet above the Pittsburg. It is classed with the Pomeroy or 8a seam which is of importance in this part of the state. The interval given was measured with a hand level.

About three-fourths of a mile northwest of Mercerville on the Wood's farm, the two coals are found, the lower or Pittsburg 1 foot thick and the Upper or Pomeroy 3 feet, the interval between the two being about 40 feet.

For the facts here stated and for many courtesies, the survey is indebted to Mr. F. B. Niday of Mercerville.

Harrison Township. The two eastern rows of sections in this township contain a valuable bed of the Pittsburg or Swan Creek coal. West of these sections the coal thins rapidly and is not workable, often in fact is not represented even by a black streak. Much the best of the coal is found in the ridge between Little and Big Bull Skin Creeks. However the coal is in good thickness on the east side of the latter creek, and is mined at several places. From this territory the coal extends east into Clay township, where as elsewhere stated it is a valuable local source of fuel.

Following is a section of the coal in the R. A. Lewis bank, section 16, in the ridge east of Little Bull Skin Creek:

		Ft.	In.
Shales, black		6	0
Soapstone		0	10
Upper bench. Coal		3	9
Clay		0	2
Lower bench	Coal	1	0
	Pyrites streak	0	½
	Coal	1	8
Clay, unmeasured.			

The Lower bench is fairly uniform in thickness but the Upper bench varies greatly, the result being marked changes in the total thickness of the seam. Thus 100 feet from the section just given the coal measures only 3 feet. The altitude of the seam at the entrance to the bank is 760 feet above sea level.

The Pomeroy or 8a coal is found here about 30 feet above the Pittsburg seam, but appears to be too thin to be of value.

Quite a number of mines are found on both sides of Big Bull Skin Creek, making the territory one of the best known mining districts in the county. These banks supply the neighboring farmers and also many tons for Gallipolis, transportation being by wagon.

Below is a section of the coal in the Irions bank, southeastern quarter of section 7:

	Ft.	In.
Shale, black	2-4	
Upper bench. Coal	0	10
Shale	0	4
Lower bench. Coal	2	10

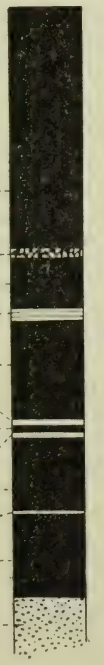
Another layer of coal is reported above the black shales referred to in the above section. It probably represents the Roof coal.

The shales above the Lower bench vary much in thickness, changing from 4 to 15 inches in the space of 20 feet.

In the Kerns bank in the northeast quarter of section 6 the coal was found as shown in Section 27.

SECTION 27

		Ft.	In.
4. Upper bench,	Coal,	2	5
	Layer of dirty coal,	0	1
	Coal,	0	6
	Parting,	0	1¾
	Coal,	0	11½
3. Parting,	Pyrites,	⅜	
	Coal,	1	
	Pyrites,	¾	
2. Lower bench,	Coal,	0	8½
	Parting,	0	¼
	Coal,	0	10
1. Clay, unmeasured,			



Two fairly persistent pyrites layers were found in this mine. Each attains a maximum thickness of 3 inches, but occasionally disappears. The seam here varies from 4 to 8 feet in thickness.

Chemical analysis and calorific value of Section 27:

Ultimate.		*Proximate.*	
Carbon	64.91	Moisture	6.98(a)
Hydrogen	5.24	Volatile Matter	36.14
Oxygen	14.60	Fixed carbon	47.85
Nitrogen	1.01	Ash	9.03
Sulphur	5.21		
Ash	9.03		
	100.00		100.00

Calorific value .....6,583 calories.

(a) Moisture in the air-dried sample about 3%.

Parts 1 and 3 of the above section were rejected in the sample which measured 4 by 2 inches.

On the Lewis farm, adjoining the Kerns on the north, the coal is similar to that given in the preceding section with an additional layer 2 feet in thickness above the shales which form the roof. This layer of coal is probably the equivalent of the one referred to in the Irions bank. It is not mined. Irregular pyrite bands are found in this mine.

In the mine of A. V. Houck the coal was found as shown in Section 28.

This section shows resemblance to the same seam in the eastern part of the state. The Roof coal has the complex structure occasionally found in Belmont and adjacent counties. The shale below the Roof coal represents the Draw slate; the Upper bench, here thin, the Breast coal; the soapstone, the Bearing in horizon, and the Lower bench the Brick and Bottom coals. Whether this coincidence is more than a lucky accident cannot be said.

This mine helps supply the surrounding country and to a small extent the county seat, Gallipolis.

Chemical analysis and calorific value of Section 28:

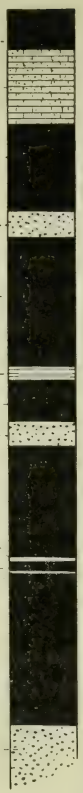
Ultimate.		*Proximate.*	
Carbon	64.59	Moisture	7.83(a)
Hydrogen	5.18	Volatile Matter	34.15
Oxygen	15.49	Fixed carbon	48.26
Nitrogen	1.09	Ash	9.76
Sulphur	3.89		
Ash	9.76		
	100.00		100.00

Calorific value .....6,544 calories.

(a) Moisture in the air-dried sample about 3%.

SECTION 28

		Ft.	In.
6. Roof coal, reported,	Coal,	0	5
	Sandstone,	0	9
	Coal,	0	10
	Soapstone,	0	3
	Coal,	1	3
5. Dark shale,		0	2
4. Upper bench,	Coal,	0	4½
3. Soapstone,		0	3
2. Lower bench,	Coal,	1	1
	Parting,	0	¼
	Coal,	0	1
	Parting, very thin,		
	Coal,	1	5¾
1. Clay,			



This sample was taken from parts 2 and 4 of the section, these being the only portions of the seam marketed.

Northeast from the Lewis bank the Pittsburg or Swan Creek coal thins and is of much less value. On the G. W. Lusher farm along the west bank of Raccoon creek in section 12 the coal was reported by the proprietor as follows:

	Ft.	In.
Upper bench. Coal	3	0
Shales	1	8
Lower bench. Coal	2	8

The 8a or Pomeroy coal is reported in this hill, and about 20 inches in thickness. A short distance up the creek it has been mined.

CHAPTER II.

THE POMEROY COAL.[1]

The Pomeroy coal has long been mined in the state of Ohio, its output having been considerable in excess of 400,000 tons in 1906. It is mined in the three counties, Meigs, Gallia and Lawrence, but from the first named only is it shipped in a large way at the present time.

Andrews classed the seam as the Pittsburg and that has heretofore been accepted as correct.[2] Study of this coal in 1907 shows, however, that the seam is not the Pittsburg but a higher one. It is the equivalent of the Redstone coal of Pennsylvania and West Virginia, and the demonstration of this point is the principal burden of the following pages.

Position and Structure of the Redstone Coal in Pennsylvania and West Virginia.

This seam was named by Rogers from the exposures on Redstone Creek, Fayette county, Pa. It has been identified at numerous places in that state and also in West Virginia, Maryland and Ohio. As will be shown later its position above the Pittsburg seam ranges usually from 20 to 55 feet.

Section on the Beachley farm, near Salisbury, Somerset county, Pennsylvania.[3]

		Ft.	In.
Surface		0	0
Redstone coal	*Coal*	0	2
	Parting	0	2½
	Coal	0	6
	Parting	0	1
	Coal	2	3
Clay		0	9
Clay, bituminous		0	2
Slate, black with nodular ore		3	0
Limestone and shale		1	3
Fire clay, impure		1	10
Limestone		10	0
Shales		10	0
Coal reported		3	0
Shale		4	0
Pittsburg coal		10	0

[1] For method of sampling see Chapter IX.

[2] Geol. Sur. of Ohio, Vol. II, p. 458.

[3] Second Geol. Sur. Penn., 3 H., p. 87.

The limestone between the two coals is reported to be more conspicuous in this territory than the Redstone coal itself.

The relation of the Redstone coal to the Pittsburg in West Virginia is shown in the following section on Scott's Run, Monongalia county.[1]

	Ft.	In.
Concealed	15	0
Coal, Redstone	4	0
Limestone, Redstone	18	0
Shale and fire clay	5	0
Slate, black	5	0
Coal, Pittsburg.		

The structure of the coal in this state is shown by the following section taken in the Century mine in Barbour county.[2]

	Ft.	In.
Draw slate	1	0
Coal	0	7
Bone coal	0	½
Coal	4	9½
Bone coal	0	4
Coal	5	0
Slate	0	⅓
Coal	0	7

This coal is found in the hills on both sides of the Ohio river in the vicinity of Wheeling, and has been identified by I. C. White as the Redston seam.[3]

The Pomeroy or Redstone Coal from Belmont to Morgan Counties.

The following section made by Mr. J. E. Hyde about one mile west of Bellaire shows the position and thickness of this seam in the extreme eastern part of the state.

	Ft.	In.
Limestone with shaly layers	4	0
Gray argillaceous shale	3	9
Pomeroy or Redstone coal, No. 8a	1	3
Gray argillaceous shale	0	9
Hard gray amorphous limestone with numerous minute fossils.	2	0
Gray shale	0	4
Limestone, hard gray amorphous with numerous minute fossils	2	3
Limestone, hard gray amorphous with some fossils	2	0
Shales, hard with some lime and fossils	2	6
Unseen	12	6
Top of Pittsburg coal, No. 8		

[1] Bull. 65, U. S. G. S., p. 47.
[2] West Va. Geol. Sur., Vol. II, p. 161.
[3] Bull. 65 U. S. G. S., pp. 49 and 50.

This section shows thick limestones between the two coals, similar to what have been reported in Pennsylvania and West Virginia. Farther west and southwest in Ohio the limestones are much thinner, but have been traced to the Ohio river at Pomeroy.

Below is a partial record of a diamond drill test made in section 10 of Wayne township in the southwestern part of Belmont county. Only that part of the record is given which shows the relative positions of the Pomeroy or Redstone and the Pittsburg coals.

	Ft.	In.
Limestone	3	4
Soapstone with lime nodules	3	0
Pomeroy or Redstone coal, No. 8a, (Coal and shale)	1	3
Fire clay	1	0
Gray shale	3	2
Black shale	1	0
Limestone	5	6
Limestone and shale	2	0
Limestone	3	0
Lime, fire clay	2	0
Gray shale with limestone nodules	3	0
Greenish shale	1	6
Dark shale, carbonaceous	3	2
Pittsburg coal — *Roof coal*	0	10
Pittsburg coal — *Draw slate*	1	0
Pittsburg coal — *Coal*	5	7
Fire clay	4	1

Frequent exposures of the seam are found in Jefferson county. The following section was measured by the late Professor C. N. Brown in section 22 of Smithfield township.

	Ft.	In.
Shales, exposed	10	0
Pomeroy or Redstone coal, No. 8a	2	1
Clay streak		
Limestone	2	0
Clay shales	11	0
Pittsburg coal (Roof coal)	2	1
Draw slate	1	0
Black slate	0	1
Pittsburg coal (Breast coal) No. 8	2	4

This section shows an interval of only 13 feet between the two seams, while in Belmont county, as the sections show, the interval is materially larger.

From Belmont county the coal can be traced southwest through Noble and Morgan counties, but in both of these the exposures of the seam are fewer and less prominent.

In his report on the Meigs Creek coal in the last two counties named in the above paragraph, Professor Brown makes occasional mention of a seam lying between the horizon of the Meigs Creek and Pittsburg

coals. Thus in Wayne township in the northeastern part of Noble county, he mentions a faint coal mark at from 50 to 55 feet below the Meigs Creek. Likewise he speaks of a thin seam of coal about 60 feet below the Meigs Creek in Elk township in the southwestern part of the county.[1] The position of the seam is from 20 to 30 feet above the horizon of the Pittsburg in the localities mentioned and it is plainly the Pomeroy or Redstone coal.

In the northern part of Meigsville township, Morgan county, Professor Brown found the Pomeroy or Redstone coal from 12 to 20 inches thick, about 26 feet above the Pittsburg seam.

West of the Muskingum river the Pittsburg and Pomeroy coals are very thin or wanting until the southwestern part of the county (Morgan) is reached where the Pittsburg coal suddenly increases in thickness and becomes a workable seam.

Structure of the Pittsburg Coal in Southwestern Morgan and Northern Athens Counties.

It will be well at this point to note the structure of the Pittsburg coal in the territory just referred to where it is commonly known as the Federal Creek seam. For the convenience of the reader a few sections will be given which have already appeared in the chapter on the Pittsburg coal.

Section of coal in the Waymer bank, near Joy in the southwestern part of Morgan county:

		Ft.	In.
Coal, Upper bench	Coal	1	6
	Bone coal	0	8
Clay or shales		0	11
Coal, Lower bench	Coal	0	2
	Parting	0	⅛
	Coal	0	7½
	Parting	0	½
	Coal	0	3
	Parting	0	⅜
	Coal	0	1½
	Parting	0	⅜
	Coal	2	0

A few miles farther south in Athens county a number of mines exist, three of which ship by rail. In the one at Broadwell the coal was found as follows:

		Ft.	In.
Coal, Upper bench	Coal	1	3
	Bone coal	0	3¼
	Coal	0	4
Clay or shales		1	0

[1] Geol. Sur. of Ohio, Vol. V, chapter XIX.

		Ft.	In.
Coal, Lower bench	Coal	0	6
	Parting		
	Coal	0	2
	Parting	0	¼
	Coal	2	5

These sections are typical for this part of the state. It will be seen that the coal consists of two benches separated by a prominent layer of shales or clay, called soapstone by the miners. This structure of the Pittsburg seam is very persistent in southern Ohio, and may be found wherever the coal exists in anything like normal thickness. It is further illustrated by sections on following pages.

The Pomeroy Coal from the Hocking River in Athens County South to the Ohio River.

In Alexander township, Athens county, the Pomeroy coal is usually found where due, though frequently it is little more than a blossom. The coal is usually about 20 feet above the Pittsburg.

Near the Bennett mine in section 4 of this township, the following section was measured:

	Ft.	In.
Shales, unmeasured.		
Pomeroy coal, No. 8a	1	0
Shales with nodular limestone	20	6
Pittsburg coal, No. 8	4	0
Shales	8	0
Sandstone, unmeasured.		

The nodular limestone mentioned in the last two sections is important in the identification of the two coals. It is rarely a foot thick, but is persistent and has been traced to the Ohio river at Pomeroy where the lower or Pittsburg coal is not represented by even a black streak. In this part of the state limestones are not common and this fact increases the value of the stratum in question for stratigraphical purposes.

Lodi township lies east of Alexander and contains the Pomeroy coal where due, the thickness usually ranging from 12 to 18 inches. Occasionally the coal is underlain by several feet of white limestone. The coal is not mined in the township except where it can be stripped.

Going south from Lodi township, Bedford township, Meigs county is reached. Here the Pomeroy seam is found about 20 feet above the Pittsburg and about 20 inches thick. It is not mined except by stripping.

On the Mayhugh farm in section 21 the coal was found as follows:

	Ft.	In.
Coal	0	8
Shales	0	10
Coal	1	8

On the same farm the lower or Pittsburg seam has been mined by stripping in the bed of a creek.

In the southeast corner of this township both coals are well shown and the locality is important in demonstrating the correct position of the Pomeroy seam. About one mile due north of the hamlet Midway the Pittsburg coal is stripped in the bed of a run on the Riggs farm, where the following section was measured.

		Ft.	In.
Shales, unmeasured.			
Coal, Upper bench		0	3
Clay or shales		1	3
Coal, Lower bench	Coal	1	0
	Shales	0	1
	Coal	1	6
	Shales	0	1
	Coal	1	6

It will be noted that the Upper bench here is thin. In fact where the coal contracts this bench suffers most and not infrequently disappears. On the hill between this stripping and Midway the upper or Pomeroy coal is found and the thin limestone below it.

On Kingsbury Creek due south of Midway the Pittsburg coal is below drainage having dipped beneath the bed of that stream about one mile farther up, where the following section was measured.

	Ft.	In.
Sandstone, unmeasured.		
Shales	2	0
Pomeroy coal	1	6
Shales, blue	8	0
Shales with limestone	11	0
Sandstone, shaly	9	0
Pittsburg coal, unmeasured.		

A few hundred yards up stream from where this section was taken the Pittsburg coal has been stripped in the bed of the creek.

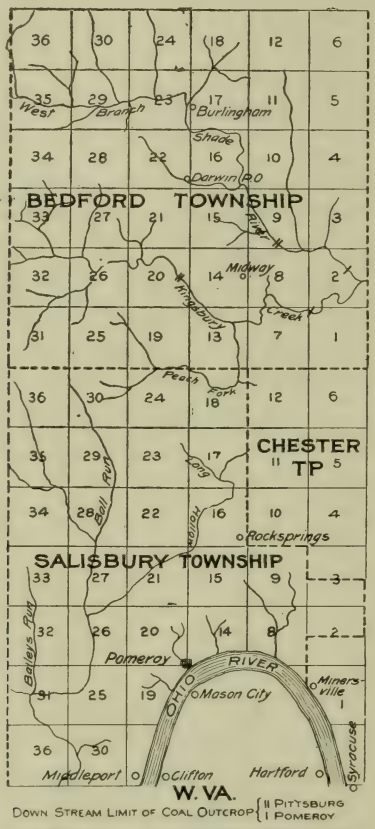
From Kingsbury Creek the Pomeroy coal can be followed up a tributary, Peach Fork, at least three miles.

In following up this tributary one crosses from Bedford township into Salisbury which contains the most valuable deposit of the Pomeroy coal above drainage in Ohio. The structure of the seam along Peach Fork on the northern edge of Salisbury township is as follows:

		Ft.	In.
Sandstone		30	0
Shales		4	0
Pomeroy coal	*Coal*	0	3
	Shales	0	1
	Coal	1	8
Shales		2+	

The coal has been worked to a very small extent by the farmers. Everywhere along this stream the Pittsburg coal is below drainage and so was not seen. At one place it was reported to have been struck in digging a well, its position being 30 feet below the Pomeroy seam.

Crossing the divide to the southwest from the head of Peach Fork the valley of Ball Run is entered and the Pomeroy coal is found in similar position and thickness to that on the first named stream. The position of the coal, immediately under the massive sandstone is important.



BEDFORD AND SALISBURY TOWNSHIPS, MEIGS COUNTY

Southward on Ball Run the coal increases rapidly in thickness and is mined in a small way at a number of places. It can easily be followed along this stream to the valley of the Ohio. Nowhere in this locality, however, was the Pittsburg coal found though conditions for its exposure are excellent. In fact it is not represented by even a black streak. At Pomeroy the persistent band of limestone which has already been referred to was found below the Pomeroy coal.

The structure as well as the thickness of the Pomeroy coal changes

to the south. On the Gilmore farm, north edge of section 28, Salisbury township, on Ball's Run, the coal was found as follows:

	Ft.	In.
Sandstone	30	0
Coal	1	6
Shales	0	6
Coal	0	4
Clay, unmeasured.		

On the south side of this section the coal measures 4 feet. Where the coal is thin in Athens and Meigs counties, it is usually divided into two parts by a layer of clay or shales. The structure then resembles that of the Pittsburg, but as has been shown the two coals are frequently found on the same hillside and so have not been confused.

The Pomeroy Coal at Pomeroy and Vicinity.

The structure of the Pomeroy coal at Pomeroy and vicinity forms a marked contrast with that of the Pittsburg seam in southern Ohio. As has already been shown the Pittsburg consists of two prominent benches of coal separated by a layer of shales or clay, this structure being very persistent. The Pomeroy seam on the other hand does not have such a characteristic structure. This is well shown by the following sections:

Section in the Logan Mine, Pomeroy.

	Ft.	In.
Bone and dirty coal	1	3
Coal	1	8
Parting less than ⅛ inch.		
Coal	0	3
Parting very thin.		
Coal	2	3
Clay, unmeasured.		

Section in the Mine of the Peacock Coal Co., Pomeroy.

	Ft.	In.
Shales, reported thickness	2	0
Impure coal	0	6½
Bone coal	0	5½
Coal	3	3

A few miles up the river the coal was found as follows:

Section in the Bartel's Mine, Syracuse.

	Ft.	In.
Sandstone, unmeasured.		
Impure coal	0	7½
Horn coal	0	5½
Coal	1	4
Horn coal	0	2½
Coal	2	3½
Clay, unmeasured.		

Still farther up the river at Antiquity the coal is mined by shafting, the seam being 100 feet below low water. The coal is as follows:[1]

	Ft.	In.
Coal with a bony band	2	6
Slate	0	2
Coal	3	0

It may not be amiss to give a section on the West Virginia side of the river. The coal was found as follows in the mine of the West Virginia Salt and Coal Company, near Hartford.[2]

		Ft.	In.
Sandstone.			
Slate			
Draw slate		0	1
Coal	Top coal	0	7
	Horn coal	0	2
	Coal	3	9

Other sections from that side of the river might be given but they would in a large measure duplicate the above.

These sections show a marked difference in structure between the Pomeroy coal and the Pittsburg as found on Federal Creek and vicinity, but a striking resemblance to the Redstone coal of Pennsylvania and West Virginia as shown in the first part of this chapter.

The Pomeroy Coal in Gallia and Lawrence Counties.

In Gallia county farther west the structure of the Pomeroy coal becomes more simple, consisting generally of a solid block, but occasionally having one or more shale parting.

Both the Pittsburg and Pomeroy coals are found in the eastern part of the western half of Gallia county. Still farther west the Pittsburg seam wholly disappears, leaving the Pomeroy the only seam in the hills and this is thin and of value for domestic purposes only.

Andrews classed the higher of the two seams as the Pomeroy, but the lower or Pittsburg seam he did not correlate with any seam found elsewhere in Ohio. As is well known he regarded the Pomeroy coal as the Pittsburg.

This field furnishes very strong evidence on the position of the Pomeroy coal, for this seam can be followed from hill to hill all the way from Pomeroy to the territory under consideration, and thus the identity of the seam in the two counties is proven.

In at least five townships in Gallia county where the Pomeroy coal exists, another seam is found from about 25 to 55 feet lower. This seam is in a number of localities much more prominent than the Pomeroy, and is known locally as the Swan Creek, Jeffers or Lewis seam. The structure of the coal is shown in the following sections:

[1] West Va. Geol. Sur., Vol II, p. 194.

[2] Ibid., p. 193.

Section in mine of the Swan Creek Coal Co., near Bladen on the Ohio river:

	Ft.	In.
Sandstone, massive.		
Shales, reported thickness	2	6
Coal, Upper bench	0	4½
Soapstone	1	0
Coal, Lower bench	2	9
Clay, unmeasured.		

The section shows the coal of the Upper bench thin. It is in fact sometimes wanting in this mine. The soapstone below also varies. Rarely is it more than a foot thick and occasionally it disappears.

Section in the mine of Samuel Lewis on Swan Creek in section 29 of Ohio township:

		Ft.	In.
Shales, unmeasured.			
Coal, Upper bench	Coal	1	3
	Shales	0	2½
	Coal	1	6
	Coal and shale	2	7
Clay		0	11
Coal, Lower bench		3	0

Here the upper bench is thicker and more complex in structure.

These two sections can be duplicated in large number and in several townships. Generally the Upper bench is thin and comparatively unimportant, but occasionally it is of more value than the Lower bench. The structure of the coal is strikingly similar to the Pittsburg coal on Federal Creek in Athens and Morgan counties, already given. In both localities the seam is divided into two benches by a bed of clay or shales. Further the relation of the seam in the two localities is similar with reference to the Ames or Crinoidal limestone. That the coal on Federal Creek is the Pittsburg there can be no doubt, and the same conclusion is necessarily reached with reference to the Swan Creek, Jeffers or Lewis seam of Gallia county.

It remains now to show the position of the Pomeroy seam in this territory with reference to the lower or Pittsburg. On or near section 28, Guyan township in the southwestern corner of Gallia county, the following section was measured with a hand level:

	Ft.	In.
Sandstone	40	0
Coal, Pomeroy or 8a	3	6
Partly covered, sandstone seen	27	0
Coal blossom, Pittsburg or No. 8		
Shales	15	0

One more section from Gallia county will be given. This is on section 26 of Clay township, and is taken from Professor Andrew's report:[1]

[1] Geol. Sur. of Ohio, Vol. I, p. 240.

	Ft.	In.
Sandstone, unmeasured.		
Pomeroy coal	1	6
Not exposed	30	0
Sandy shale	10	0
Clay shale	3	0
Top coal	2	0
Ferruginous black slate	2	0
Coal — *Coal*	0	10
Coal — *Clay*	1	0
Coal — *Coal*	3	6
Clay	2	6

While Andrews does not name the lower coal, it is clear from his text that he regards it as the Jeffers seam, which as has elsewhere been stated is the Pittsburg. In fact this section was taken at the mine of Abram Jeffers. The "Top coal" of the section is what is elsewhere known as the Roof Coal of the Pittsburg seam.

In Lawrence county the Pittsburg coal is rarely seen and probably is never more than a black streak. The following section was obtained in the northwest quarter of section 25 of Mason township:

	Ft.	In.
Sandstone	25	
Shales	11	0
Coal, Pomeroy	4	0
Fire clay	2	0
Limestone	1	0
Shales	19	0
Coal blossom, Pittsburg	0	6
Fire clay	1	0

Not only does this section show both coals but also the limestone between them, which as has already been stated, is important in identfying the two seams.

Conclusion.

To the writer the proof is conclusive, the Pomeroy coal lies above the Pittsburg and is the equivalent of the Redstone seam. Since, however, the name Pomeroy is in general use in Ohio it will be retained. The Pittsburg coal being known as No. 8 and the Meigs Creek as No. 9, the Pomeroy seam may appropriately be numbered 8a. For the massive sandstone overlying the Pomeroy coal, the name Pomeroy is proposed.

THE POMEROY COAL IN MEIGS COUNTY.

The Pomeroy coal is at its best in this county. It is found above drainage wherever due and in the southern part becomes one of the important coal fields of the state.

In the northern part of the county the seam is underlain by the

PLATE III. The Pomeroy Sandstone and Coal at Pomeroy. The Sandstone lies directly over the Coal.

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Pittsburg, and between them is usually found a thin bed of limestone. Farther south the Pittsburg coal entirely disappears.

Overlying the Pomeroy coal is a massive sandstone for which the name Pomeroy is proposed. Sometimes it rests directly on the coal, but occasionally it is separated from the coal by a bed of shales of varying thickness. The sandstone is persistent, being found over extensive areas.

Salisbury Township. This township has been an important source of fuel from almost the time of settlement of the territory. Then as now salt making was a leading industry and naturally coal was used quite largely as fuel. The river provided cheap transportation and the coal was shipped to Cincinnati and other river markets. With the construction of railroads a direct outlet has been provided to the Great Lakes and the Northwest. This has resulted in the opening of new mines and a large increase in coal production.

Throughout the township the coal lies either directly under the Pomeroy sandstone or is separated from it by a thin bed of shales. A few feet below the coal there is found the thin stratum of limestone which is so persistent between the Pittsburg or No. 8 and the Pomeroy or 8a seams. This limestone was found within the city limits of Pomeroy, showing that the stratum in question reaches as far south at least as the Ohio River.

The township is a larger producer of the Pomeroy or 8a coal than any other township in Ohio. Along the eastern line of the township the coal is under cover except on the Ohio River and two or three tributary streams. On the western side of this township the coal is high in the hills, but is mined for railroad shipment as far west as the vicinity of Rutland.

In the northwestern part of the township the coal is thin and of little value, but farther south and east the seam thickens rapidly, and soon becomes of decided value.

In the northern part of the township the coal is thin but persistent and uniform in thickness. From Pomeroy the Pomeroy or 8a coal may be traced with scarcely any break north into Bedford township where the No. 8 coal, about 20 feet lower becomes workable. Along Peach Fork in the northern part of the township the 8a coal outcrops under the sandstone continuously for several miles and has been mined in a very small way at many places. The following section shows the structure of the coal along this stream.

	Ft.	In.
Sandstone	30	0
Shales	4	0
Coal	0	3
Shales	0	1
Coal	1	8
Shales, blue	2+	

In the same vicinity the Pittsburg or No. 8 coal was reported to have been found in a well 30 feet below the 8a coal.

Section 29 shows the coal as found in the mine of the Peacock Coal Company at Pomeroy.

SECTION 29

	Ft.	In.
5. Shale, reported thickness,	2	0
4. Impure coal,	0	6½
3. Bone coal,	0	5½
2 Coal,	3	3
1. Clay, unmeasured,		

The mine is an old one, having been first worked about the time of the Civil war. In the hill facing the river the coal has been worked out, and mining is now done farther back. During the past few years the coal has been cut by machinery, but prior to that time the work was done by hand.

Where this coal is used in the salt furnaces the impure and bone coal are both retained, but when the fuel is shipped both are thrown out. No regular bands of pyrite were noticed, but irregular pieces of this exist near the base of the coal.

Chemical analysis and calorific value of Section 29:

Ultimate.		*Proximate.*	
Carbon	66.71	Moisture	7.33(a)
Hydrogen	5.53	Volatile Matter	34.59
Oxygen	15.96	Fixed carbon	49.39
Nitrogen	1.06	Ash	8.69
Sulphur	2.05		
Ash.	8.69		
	100.00		100.00

Calorific value ..... 6725 calories.

(a) Moisture in the air-dried sample about 4%.

The sample included only part 2 of the above section. No pyrites occurred in the sample but is occasionally found in the seam especially near the bottom. The sample was about 5½ inches wide and 1½ inches deep.

Section 30 was measured in the Logan mine at Pomeroy.

SECTION 30

	Ft.	In.
7. Bone and dirty coal,	1	3
6. Coal,	1	8
5. Parting, less than ⅛ inch,		
4. Coal,	0	3
3. Shale parting, very thin,		
2. Coal,	2	3
1. Clay, unmeasured,		

The upper 15 inches of the coal are mined but usually not mixed with the main body of the seam. The coal supplies a local market only. The altitude of the seam at the entrance to this mine is 613 feet.

Chemical analysis and calorific value of Section 30:

Ultimate.		*Proximate.*	
Carbon	66.47	Moisture	7.22(a)
Hydrogen	5.39	Volatile Matter	32.82
Oxygen	16.43	Fixed carbon	50.67
Nitrogen	1.10	Ash	9.29
Sulphur	1.32		
Ash	9.29		
	100.00		100.00

Calorific value.....6668 calories.

(a) Moisture in the air-dried sample about 4%.

This sample included the entire seam because it is all commonly marketed. The section measured 7 by 2 inches.

The Pittsburg mine at the upper end of Pomeroy is not above the high water mark of the Ohio river and the mine was flooded in the spring

of 1907. As a result a "squeeze" took place along about 500 feet of the entry. The fire clay at the bottom of the coal softened and was pressed out by the weight of the overlying rock, and the track with cars on it was flattened against the roof.

One more section of the coal in this township will be given. This is from the mine of W. D. Edwards near Hobson station, and is shown in Section 31.

SECTION 31

	Ft.	In.
9. Horn and dirty coal,	1	10
8. Coal,	0	9
7. Horn coal,	0	¾
6. Coal,	0	10
5. Impure coal,	0	¼
4. Coal,	2	6
3. Impure coal,	0	¼
2. Coal,	1	9½
1. Clay, unmeasured,		

At 18 and 27 inches above the base of the coal streaks of pyrites were noticed, but these did not appear persistent. The coal supplies a local market and is shipped in a small way by rail. The latter method requires hauling by wagons from the tipple to a switch where the coal is shoveled into cars. In this locality the seam is well up in the hill.

Chemical analysis and calorific value of Section 31:

Ultimate.		*Proximate.*	
Carbon	65.55	Moisture	5.51(a)
Hydrogen	5.40	Volatile Matter	38.19
Oxygen	13.35	Fixed carbon	45.72
Nitrogen	0.95	Ash	10.58
Sulphur	4.17		
Ash	10.58		
	100.00		100.00

Calorific value.....6661 calories.

(a) Moisture in the air-dried sample about 4%.

This entire seam is marketed and for this reason was included in the sample, except a few inches at the top where the sandstone wedged in. The sample measured about 7 by 1 inch.

Rutland Township. This township probably ranks next to Salisbury in the production of the Pomeroy or 8a coal. The territory is largely drained by Leading Creek and its tributaries which have perhaps cut out one-half of the seam.

The best coal of the township is found in the three southern rows of sections. Farther north the coal thins rather abruptly, and the Pittsburg or No. 8 seam commences to increase in thickness.

The K. & M. R. R. furnishes good shipping facilities, and the coal is mined in a large way as far west as Rutland.

Section 32 was taken in the mine of Maynard Brothers about one mile south of Rutland.

This mine was opened in 1905 and has a daily capacity of 300 tons. Mining is done with pick and shipment is by rail. No pyrites was seen and it was reported quite rare.

Chemical analysis and calorific value of Section 32:

Ultimate.		*Proximate.*	
Carbon	65.29	Moisture	7.63(a)
Hydrogen	5.20	Volatile Matter	33.33
Oxygen	15.72	Fixed carbon	48.11
Nitrogen	1.03	Ash	10.93
Sulphur	1.83		
Ash	10.93		
	100.00		100.00

Calorific value.....6512 calories.

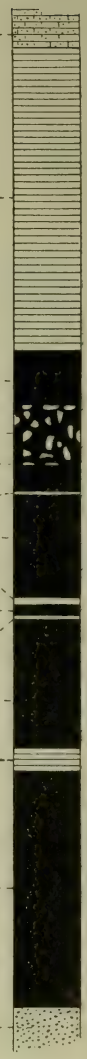
(a) Moisture in the air-dried sample about 4%.

The sample included parts 2, 3, 4, 8, 9, 10 and 12 of the section. No pyrites was noted in the sample and was reported to occur rarely. The sample measured about 5½ by 1 inch.

The northern boundary of the workable Pomeroy coal is usually

SECTION 32

	Ft.	In.
14. Pomeroy sandstone, unmeasured,		
13. Shale,	3	0
12. Top coal,	0	6
11. Impure coal,	0	7
10. Coal,	0	3
9. Parting,	0	¼
8. Coal,	1	0
7. Parting,	0	1
6. Coal,	0	1
5. Shale, parting,	0	⅜
4. Coal,	1	3
3. Splint coal,	0	2¾
2. Coal,	2	4
1. Clay, unmeasured,		



rather sharp and well defined. Near the boundary the coal is often found in an abnormally large thickness with several shale partings unknown in the principal territory of the seam. These features are well shown in the John Musser bank on Hysell Run about 2 miles northeast of Rutland. The structure of the coal there is as follows.

	Ft.	In.
Dark shale, unmeasured.		
Coal	1	6
Shale	1	6
Coal	1	2
Shale	0	1
Coal	2	0

	Ft.	In.
Shale	0	2
Coal	2	9
Fire clay, unmeasured.		

A few hundred yards north of this mine the coal is said to be less than two feet in thickness.

In the valley of Little Leading Creek, two miles north of Rutland, a lower coal, probably the Patriot lies at an altitude of 600 feet where it is mined on the Chase farm. A section of the coal furnished by a farmer is as follows:

	Ft.	In.
Coal	1	2
Shale	1	6
Coal	1	4

In places the shale parting disappears leaving 4 feet of coal.

At Langsville the Cambridge limestone is at an elevation of 580 feet, and the K. & M. R. R. is tunneling at this horizon. The Pomeroy coal in the hills north of Langsville is usually less than 30 inches thick.

At Rutland the interval between the Ames limestone and the Pomeroy coal is 151 feet, aneroid measurement. At the same place the white limestone beneath the Pomeroy coal attains a thickness of over 18 inches. Between Pomeroy and Rutland no limestone was observed at all, and it is apparent that in this locality the rock is not abundant.

In the southwestern part of the township the dip of the strata is in places over 33 feet per mile to the southeast.

Sutton Township. The Pomeroy or 8a coal is everywhere below drainage in this township except in the southwestern part in the valley of the Ohio River and a tributary stream.

Section 33 shows this seam as found in the mine of W. F. Bartels at Syracuse.

The impure coal at the top is sometimes marketed and at other times rejected. Streaks of pyrites were found at 12 and 21 inches above the bottom of the seam. The fuel is marketed locally and also shipped by rail. The seam lies 80 feet below the valley of the river and is reached by a slope.

Chemical analysis and calorific value of Section 33:

Ultimate.		*Proximate.*	
Carbon	65.29	Moisture	4.85(a)
Hydrogen	5.32	Volatile Matter	36.28
Oxygen	12.76	Fixed carbon	46.35
Nitrogen	1.17	Ash	12.52
Sulphur	2.94		
Ash	12.52		
	100.00		100.00

Calorific value.....6624 calories.

(a) Moisture in the air-dried sample about 4%.

SECTION 33

	Ft.	In.
7. Pomeroy sandstone, unmeasured,		
6. Impure coal,	0	7½
5. Horn coal,	0	5½
4. Coal,	1	4
3. Horn coal,	0	2½
2. Coal,	2	3½
1. Clay, unmeasured,		

The sample included the entire section, though the upper 7½ inches are sometimes rejected in shipment.

Salem Township. The Pomeroy coal in this township lies at an altitude of from 850 to 950 feet and is limited to a few hills in the three southeastern sections. The thickness of the coal is nowhere reported to be over 30 inches.

Near Hanesville at the township line, the following section was measured.

Top of hill.	Ft.	In.
Sandstone, soft, coarse	18	0
Shale	5	0
Coal, Pomeroy	1	8
Shale, with limestone nodules partly covered	25	0
Clay, red	11	0
Sandstone	4	0
Shale, red	31	0
Shale with limestone	2	6
Shale, sandy	8	0
Clay, red with nodular ore and limestone	35	0
Shale, gray	5	0
Sandstone	3	6
Shale, partly covered	14	0
Ames limestone, impure	1	6
Shale calcareous	34	0
Limestone with red cherty iron ore	2	0
Sandstone	4	0
Clay, red (partly covered)	13	0

	Ft.	In.
Sandstone, shaly	22	0
Cambridge limestone	2	1
Coal, impure	2	0
Shale	12	0

The Ames limestone is impure and has few fossils. The coal below the Cambridge limestone in places reaches 30 inches in thickness but is usually very impure.

In sections 6 and 12 the strata in the high ridge show an anticlinal structure, the axis of which appears to run very nearly north and south.

Scipio Township. This lies west of Bedford and contains both the Pittsburg and Pomeroy seams, the interval between the two ranging from 14 to 20 feet. The Pittsburg is the important seam in the northern half of the township, but it thins to the south where the Pomeroy becomes the thicker seam.

Near Downington P. O. the two coals were found as follows:

Sandstone, unmeasured.	Ft.	In.
Pomeroy coal No. 8a	1	8
Calcareous shales	15	0
Pittsburg coal, No. 8	3	0
Shales	15	0

In the northern part of the township the Pomeroy coal is usually less than 20 inches thick, but in the southeastern part it varies from 24 to 30 inches. It scarcely needs be said that the seam in this township is of little importance.

Bedford Township. The Pomeroy coal is quite uniform throughout this township both as to thickness and also with reference to the interval between it and the Pittsburg coal. The thickness of the Pomeroy seam is usually about 20 inches and the interval between the coals 20 feet. The Pomeroy coal is seldom mined except where conditions are favorable for stripping.

On the Mayhugh farm, in section 21, the Pomeroy coal is as follows:

	Ft.	In.
Coal	0	8
Shale	0	10
Coal	1	8

The Pittsburg or No. 8 coal outcrops about 20 feet below.

The following section shows the remnant of the Pomeroy coal in the northwest corner of section 12.

	Ft.	In.
Sandstone	25	0
Shale	4	6
Coal	0	1
Shale	0	3
Coal	0	3
Shale	7	0

Near the eastern edge of section 20 the two coals were found as follows:

	Ft.	In.
Sandstone	4+	
Shales	2	0
Pomeroy coal, No. 8a	1	6
Shales, blue	8	0
Shales with nodular limestone	11	0
Shaly sandstone	9	0
Pittsburg coal, No. 8	2	6+

This section shows an interval of 28 feet between the two coals. rather large for this territory.

THE POMEROY COAL IN ATHENS COUNTY.

While the Pomeroy coal is occasionally seen in the hills along or near the south bank of the Hocking River, it is little more than a streak until Alexander and Lodi townships are reached. Even there it is of little importance.

Alexander Township. The Pomeroy coal, like the Pittsburg, is rather uncertain and variable in this township. However, a blossom of the seam may nearly always be found where due while the Pittsburg coal may occasionally disappear entirely. The interval between the two coals is usually 20 feet which consists of shales often containing much white limestone. The Pomeroy coal is usually too thin to be of any importance but the Pittsburg coal is in places 4 feet thick.

Lodi Township. The Pomeroy coal is from 12 to 18 inches thick in this township and is often underlain with several feet of white limestone which is very useful for road building.

Near the south edge of section 16, the following measurement was taken along a stream:

	Ft.	In.
Shale, sandy, unmeasured.		
Shale, dark	7	0
Coal	1	6
Shale, dark	1	6
Limestone	5+	

The Pomeroy sandstone is nearly always present.

The downstream limit of outcrop of the Pomeroy coal on the Middle Branch of Shade River is in section 1. A thickness of 18 inches is reported where the coal has been stripped in this part of the township.

THE POMEROY COAL IN GALLIA COUNTY.

The seam is usually found in this county wherever due but sometimes it is little more than a prominent streak. Generally, however, it is of workable thickness.

Along the Ohio River in the western half of the county the lower or Pittsburg coal is usually the most prominent. Farther west this seam thins and rapidly disappears. Occasionally the two coals are of workable thickness in the same hill, as near Mercerville.

The structure of the Pomeroy seam in this county is very simple. Occasionally it consists of a solid block, that is without partings, but quite often it has a thin parting near the middle.

The roof is similar to that at Pomeroy and vicinity. Sometimes the sandstone rests directly on the coal but at other places the two are separated by a bed of shales.

While the seam in this county will never be the source of a large production of coal, it will long continue to yield an adequate supply for the citizens.

Cheshire Township. This township contains much valuable coal and several new mines are preparing to begin operating.

In the southwestern quarter of the township the coal is well up in the ridges but has a good thickness and is mined in a small way on nearly every farm. Some of the coal is hauled to Bidwell in Springfield township.

In the I. N. Smith bank, near the center of section 26, the structure of the coal is as follows:

	Ft.	In.
Shales, bluish, unmeasured.		
Coal	1	5
Clay streak		
Coal	0	3
Horn coal	0	1½
Coal	1	9
Fire clay, unmeasured.		

The coal is unusually hard and rather flinty. It has a firm shale roof.

In the Halfhill bank, near the western edge of section 21, the following section was taken:

	Ft.	In.
Shales, unmeasured.		
Coal	0	6
Shales	0	4
Coal	1	4
Shaly streak		
Coal	1	8
Pyrites band	0	1
Coal	0	6
Clay	0	5½
Coal	0	2½
Fire clay, unmeasured.		

This section is typical of the coal through the greater part of the township.

In the mine of the Minshall Coal Company at Carlton the coal was found as represented in Section 34.

SECTION 34

		Ft.	In.
9.	Shale, unmeasured,		
8.	Coal,	0	3
7.	Parting,	0	3/8
6.	Coal,	0	2
5.	Parting,	0	1/4
4.	Coal,	0	2
3.	Parting,	0	5/8
2	Coal,	3	6
1.	Clay, unmeasured,		

Chemical analysis and calorific value of section 34:

Ultimate.		*Proximate.*	
Carbon	62.95	Moisture	8.21(a)
Hydrogen	5.48	Volatile Matter	34.23
Oxygen	16.91	Fixed carbon	46.10
Nitrogen	1.02	Ash	11.46
Sulphur	2.18		
Ash	11.46		
	100.00		100.00

Calorific value.....6387 calories.

(a) Moisture in the air-dried sample about 4%.

The sample included everything shown in the section except parts 1, 3 and 9.

Near the southern edge of the township, the coal is less thick than the normal and continues thinning to the south into Addison township. In the Matthews bank near the center of section 13, the coal has an altitude of 725 feet and a thickness of 38 inches with two shale and pyrites streaks.

At Kyger in the eastern part of the township the Pomeroy coal is underlain by a 20-inch bed of white limestone.

Morgan Township. The Pomeroy coal is confined to the eastern row of sections in this township and lies at an altitude of nearly 900 feet.

It is workable in sections 2 and 3 and is mined in a small way by the farmers. A thickness of 4 feet is reported.

Springfield Township. A few hills in the eastern part of this township extend above the horizon of the Pomeroy coal but the seam is not found in workable thickness.

Addison Township. This small township has been eroded by a large preglacial stream making the area of the Pomeroy coal comparatively small.

Most of the coal of the township is less than 30 inches thick. South of Campaign Creek, a stream flowing southeast across the middle of the township, a thickness of 30 inches is unusual. In the northwestern part of the township in sections 35 and 36 considerable coal was formerly mined, a thickness of 36 inches being reported.

In section 36 the Ames limestone was found to be 167 feet below the Pomeroy coal by aneroid measurement. The limestone at this point is impure, ferruginous, and contains a few crinoids and numerous cephalopods.

The Pomeroy or 8a coal has been mined on the land of L. Davis in the southwest corner of section 19. The coal was found as follows:

	Ft.	In.
Sandstone, thin-bedded, over 4 feet.		
Shales	2	0
Coal	0	6
Shales	0	½
Coal	2	0

Gallipolis Township. Only the hill tops in this township contain coal, and that is the 8a or Pomeroy seam. The No. 8 or Pittsburg coal is occasionally represented by a black streak, but was nowhere found of workable thickness.

The Pomeroy coal is thin but has been mined at several places in this township both west and northeast of Gallipolis. However, the mines have been small and the quantity of coal removed unimportant. Along Paint Creek, west of Gallipolis, this seam lies 190 feet (aneroid measurement) above the Ames limestone.

Northeast of Gallipolis the area of the seam is larger, but the quantity of coal is small. Near the mouth of Mill Creek in section 23 the coal has been mined in a small way. A thickness of 30 inches is reported. In the same hill the following section was measured with the aneroid:

	Ft.	In.
Pomeroy sandstone	40	0
Pomeroy coal	2	6
Unseen	116	0
Coal blossom		
Blue nonfossiliferous limestone, quite persistent	1	8

The altitude of the Pomeroy coal is here 699 feet.

Green Township. The coal of this township is well up in the hills and lies in numerous small islands. Many country banks have been opened at various times, but very few continue in operation. A thickness of 2 feet is unusual and as the Pittsburg coal is available in parts of the township little attempt is made to work the Pomeroy seam.

Near Northup the interval between the Cambridge limestone and the Pittsburg coal was measured with a hand-level and found to be 230 feet. No trace of the Ames limestone was observed.

Walnut Township. There are a few outliers of the Pomeroy coal, which lie high in the hills, in the southeastern part of the township. The coal is seldom thick enough to be worked, and has very little cover.

Sand Fork, a tributary of Symmes Creek, has eroded its valley below the Cambridge limestone. The Ames limestone is probably absent as no trace of it was seen in the township. Likewise the Pittsburg coal is absent, no trace of it having been noted.

Ohio Township. The coal lies quite low in this township and the principal outcrop is along the Ohio Valley and Swan Creek. The Pomeroy coal is seldom mined except by stripping as the thickness is rarely over 18 inches. The Pittsburg coal lies about 30 feet below and has been mined in many places.

Clay Township. The conditions in Clay township are much the same as in Ohio township. The Pomeroy coal is usually present but is of little value owing to its thinness.

Perry Township. The Pomeroy coal is confined to two extremely high hills in the southeastern part of the township. The region all around has been much lowered by a large preglacial stream and by Symmes and Raccoon Creeks. It is remarkable that a hill of such height should be left. Popular Knob, the larger of the two hills has an altitude of 1025 feet. The Pomeroy coal has been mined in the hill and has an altitude of 950 feet. The Cambridge limestone, by aneroid measurement, lies 270 feet below the coal.

Harrison Township. About one-half of Harrison township is underlain with the Pomeroy coal. The western part, as a rule has a fair thickness, but toward the east the Pomeroy seam thins and the Pittsburg acquires a workable thickness. In the western half, scarcely a trace of the Pittsburg coal was seen.

In the western row of sections the Pomeroy coal has long been mined for local use. The seam is reported to be 3 or 4 feet thick with no partings.

In the eastern part of the township the Pomeroy coal lies from 30 to 35 feet above the Pittsburg seam and is seldom over 2 feet thick.

Guyan Township. The Pomeroy coal lies rather low in Guyan township and as a result outcrops only along the deeper valleys. Nearly every farm along Indian Guyan Creek and its tributaries has an open-

ing where coal has been taken out. The thickness ranges from 2 to 4 feet and is usually without any partings.

Near the head of Rocky Fork, northwest quarter of section 28 on the Clary farm, the coal is as follows:

	Ft.	In.
Black shales, unmeasured.		
Coal	3	6
Fire clay, unmeasured.		

The base of the coal has an altitude of 840 feet. In the same vicinity the following section was measured with the hand-level:

	Ft.	In.
Clay with limestone nodules	15	0
Clay, red	25	0
Shales, gray	10	0
Sandstone, coarse grained	20	0
Shales	20	0
Clay, red	25	0
Shales with nodular limestone	10	0
Sandstone, massive	40	0
Coal, Pomeroy or 8a	3	6
Partly covered, sandstone seen	27	0
Coal blossom, Pittsburg or No. 8		
Shales, calcareous	25	0
Sandstones, massive	15	0
Bed of stream.		

For a distance of two miles east from where the above section was taken the dip of the Pomeroy coal was found to be 40 feet per mile.

The coal has a thickness of 4 feet on the Houck farm in section 35.

In the Belleville bank, section 27, the following measurement was made:

	Ft.	In.
Sandstone	15	0
Shales, gray	4	0
Shales, dark	10	0
Coal	0	6
Shales	1	6
Coal	3	0
Fire clay.		

The Pittsburg coal is not mined anywhere in the township, and so far as has been demonstrated it is usually thin or entirely wanting.

THE POMEROY COAL IN LAWRENCE COUNTY.

The Pomeroy coal is found in several townships in the eastern part of the county where it forms the well-known "Greasy Ridge" seam. The coal lies near the tops of the hills and the area is small.

In structure the seam is similar to that in Gallia county, consisting at times of a solid block of coal and occasionally of coal with one or more thin partings. The Pittsburg seam is never represented by more than a streak.

Mason Township. The surface of this township is mostly highland. The western portion is drained by Symmes Creek, and Sand Fork a tributary of the former heads in the southeastern part and flows north. The Pomeroy coal is an important local source of fuel. The coal is present in the higher hills along Sand Fork and in the dividing ridge between that stream and Symmes Creek. The Pittsburg coal is not workable in any part and is usually entirely wanting.

In the northeast corner of section 16, the Pomeroy coal has long been mined by the farmers. In the Massie bank, the structure is as follows:

	Ft.	In.
Sandstone	10+	
Coal	5	0
Shales, unmeasured.		

The above section shows the typical structure of the coal. The thickness is somewhat above the average but the solid seam with no partings is quite characteristic of the Pomeroy coal in Gallia and Lawrence counties.

In the Watson bank, southeast corner of section 24, the structure of the Pomeroy coal is as follows:

	Ft.	In.
Sandstone, massive, unmeasured.		
Shales	5	0
Coal	1	10
Shales	1	10
Coal	4	0
Shales	0	8
Coal	0	3
Fire clay, unmeasured.		

The base of the coal in the Watson bank has an altitude of 860 feet. The partings in the coal at this point are very similar to those found in the Pomeroy coal in Rutland township, Meigs county.

The following section was taken in the northwestern quarter of section 25:

	Ft.	In.
Sandstone	25+	
Shales	11	0
Coal, Pomeroy	4	0
Fire clay	2	0
Limestone	1	0
Shales	19	0
Coal blossom, Pittsburg	0	6
Fire clay	1	0
Sandstone, unmeasured.		

Windsor Township. The eastern and western parts of this township are deeply eroded by Indian Guyan and Symmes Creeks respectively. The Pomeroy coal is confined to the highlands between the two streams and a few outliers east of Indian Guyan Creek. The ridge running north and south between Indian Guyan and Symmes Creeks is known locally as Greasy Ridge, and the Pomeroy coal is there called the Greasy Ridge coal. This seam is mined in many places along the ridge and supplies the country for miles around.

The following section was taken in the Dillon bank near the center of section 4:

	Ft.	In.
Sandstone over 20 feet.		
Shales	3	0
Coal	3	10
Shales, unmeasured.		

In section 9 coal is mined on the Holderby and Capper farms. A thickness of 4 feet is reported. The altitude of the coal is there 917 feet.

The eastern row of sections contains the Pomeroy coal but with an inferior thickness.

In the southwestern corner of section 28, a 30 inch ledge of white limestone was seen at an altitude of 685 feet.

Rome Township. More than one-half of this township is underlain with the Pomeroy or 8a coal but the seam is usually too thin to be workable. The Pittsburg coal is nowhere present.

For many years the Pomeroy coal has been mined in a small way on the east side of Paddy Creek, one mile northeast of Labelle. In places the coal attains a thickess of 40 inches. There are no regular partings, but lenticular pyrite boulders, often having a diameter of 14 inches, abound in the body of the coal.

On Federal Creek in section 23, the coal attains a workable thickness. The Nichols farm in section 17 on the river front, has the Pomeroy coal with a thickness of 2 feet. The western row of sections contains only a moderate quantity of coal.

Union Township. The surface of this township is much lowered by the broad valleys of Symmes and Indian Guyan Creeks and their tributaries, therefore very little of the Pomeroy coal is left in the hills. West of Symmes Creek a workable thickness has not been found. As for the remainder of the township a thickness of 36 inches is unusual. The Pittsburg coal is wanting in all parts.

On the J. Suiter farm in section 23 the Pomeroy coal is only 24 inches thick. In section 2, on the Brammer farm, the seam has a thickness of 36 inches; however there is so little cover that the coal is much weathered. In sections 1, 12, 13 and 24 the quantity of Pomeroy coal is very moderate.

The Cambridge limestone is above drainage on Symmes Creek. The coal beneath the limestone is stripped in places for local use.

Fayette Township. The Pomeroy coal is limited to a few of the highest ridges in this township, and is not workable in any part. The Pittsburg coal is entirely wanting.

Throughout the greater part of the township the Cambridge limestone is above drainage. The following measurement was made in section 23:

	Ft.	In.
Shales, unmeasured.		
Cambridge limestone	1	6
Shales	1	0
Coal	0	10
Shales	5	0
Limestone, nonfossiliferous	1	0

The lower layer of limestone of the above section has been noticed as far north as Athens county.

In the following section which was measured with the hand level on the river bluffs at Burlington, the nature of the strata lying below the Ames limestone is shown:

	Ft.	In.
Ames limestone	2	9
Shales with limestone nodules	20	0
Coal	0	10
Shales	5	6
Coal	0	5
Shales with ferruginous limestone	7	0
Sandstone, thin-bedded	11	0
Unseen	13	0
Sandstone	1	6
Unseen	22	0
Sandstone	2	0
Shales	2	0
Sandstone	2	9
Shales	5	6
Coal, shaly	5	6
Sandstone, massive	63	0

The Ames limestone is impure and sandy but highly fossiliferous. The rocks for a distance of over 200 feet above this formation were well exposed, but no trace of the Pomeroy or Pittsburg coals was found.

CHAPTER III.

THE MEIGS CREEK COAL.[1]

This seam is regarded the equivalent of the Sewickley of Pennsylvania. It was named Meigs Creek by the late Professor C. N. Brown because that stream drains the central part of the territory.[2]

The position of the seam is usually from 80 to 100 feet above the Pittsburg. This has been made clear from the sections given in the chapters devoted to the Pittsburg coal and is further demonstrated in the pages which follow.

While the coal is due in the hills all the way from Jefferson to Lawrence counties, it is found in workable quantities only in Belmont, Harrison, Monroe, Washington, Noble and Morgan counties.

The coal lacks the persistence and regularity of its neighbor, the Pittsburg or No. 8 seam. Sometimes it is divided into two parts or benches by a prominent bed of shales or clay, but more often this structure is wanting. Sometimes the seam is without any parting, but usually one or more bands of shale, clay or pyrites is found. Both floor and roof are irregular, rising or dipping and thus modifying the thickness of the seam. Especially is this true of the roof which in a short space may occasionally entirely cut out the coal.

These features indicate that conditions were not uniform during the deposition of the coal and the rock which forms the roof. Probably these deposits were laid down in coastal swamps or marshes that were partly disconnected, the conditions of deposition being slightly different in the different basins.

The absence of the coal where due may be a result of water too deep to permit of the coal plants flourishing, or just the reverse, that the water was so shallow the vegetation after falling was not properly submerged. The latter appears more probable for with deeper waters marine fossils might be expected.

The quality of the coal is inferior to the Pittsburg, as the analyses will show. In spite of these disadvantages, however, the seam is an important one, and its value will increase as the great seam below is more and more worked out.

THE MEIGS CREEK COAL IN HARRISON COUNTY.

This seam is found in workable thickness and quantity in two townships only, Athens and Short Creek. However, it may occasionally

[1] For method of sampling see Chapter IX.

[2] Geol. Sur. of Ohio, Vol VI, p. 1059.

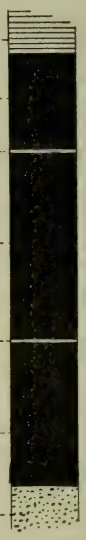
be seen in the highest hills in other townships and especially in the vicinity of Cadiz, where it is reported to have been formerly worked in a very small way. Its interest in that locality, however, is geological rather than commercial. The seam usually lies from 70 to 90 feet above the Pittsburg coal.

Athens Township. A large acreage of the Meigs Creek coal exists in this township. In the northwestern part it is found in the highest hills only, while in the eastern and southeastern parts it is much more extensive. The seam is everywhere above drainage in this township, has long been worked by the farmers and is an important source of fuel.

On land of Joshua Kirk, one mile west of New Athens, Section 35 of the coal was taken.

SECTION 35

	Ft.	In.
7. Shale, unmeasured,		
6. Coal,	0	11
5. Parting,	0	¼
4. Coal,	1	10
3. Parting,	0	¼
2. Coal,	1	5
1. Fire clay, unmeasured,		



Chemical analysis and calorific value of Section 35:

Ultimate.		*Proximate.*	
Carbon	68.67	Moisture	5.35(a)
Hydrogen	5.21	Volatile Matter	33.09
Oxygen	12.38	Fixed carbon	51.27
Nitrogen	1.25	Ash	10.29
Sulphur	2.20		
Ash	10.29		
	100.00		100.00

Calorific value.....6885 calories.

(a) Moisture in the air-dried sample about 2%.

The sample included the entire section except parts 1 and 7.

The following section of the coal was measured in the Culbertson bank, south of the village, New Athens:

	Ft.	In.
Shale and impure coal	2	0
Soapstone	1	8
Bone coal. Rejected	0	2
Top coal	2	11
Shale	0	¼
Bottom coal	1	4
Soapstone	2	0

An average thickness of 4½ feet is claimed for the coal in this mine. Many lenticular nodules of pyrite are found, and are thrown out in mining. The bone coal and soapstone above are removed leaving the overlying shales and impure coal to form the roof. The bearing in is made between the Top and Bottom coals, and then the former is shot from above and the latter from below.

On an average four men are kept at work in this mine during the year, supplying the village New Athens and the neighboring farmers much of their fuel.

The Meigs Creek coal has been more extensively worked in this township than elsewhere in the county, scores of openings having been made, but few of these are kept in working order.

The coal does very well as a fuel for domestic purposes, but because of the large quantity of ashes resulting, some regard the Pittsburg coal as the more economic though it costs more per ton.

Short Creek Township. Small patches of the Meigs Creek coal are found in the hill-tops in the northern part of the township. To the south, however, it forms almost a continuous bed, being removed in the deeper valleys only. It is an important source of fuel to the farmers in this locality, since the Pittsburg seam is everywhere below drainage. The coal makes a hot fire, but is high in ash.

On the Lodge farm in section 16, the following measurement of the seam was made:

	Ft.	In.
Shales	3	0
Coal	2	9
Slate parting very thin, sometimes absent		
Coal	1	3

The thickness of the seam in this mine ranges from 3 ft. 8 in. to 4 ft. 6 in. The Meigs Creek coal in this township forms a valuable deposit of fuel which some day will be extensively mined. The Pittsburg seam, however, must be removed first.

Lying in the tops of the highest hills is found another seam, No. 10. It is reported to have formerly been worked in the hill at Harrisville. Its place is about 100 feet above the Meigs Creek coal.

THE MEIGS CREEK COAL IN BELMONT COUNTY.

This county contains a larger area of the Meigs Creek coal than any other county in the state. The seam is found in every township, but in those in the northwestern part it has been largely removed by erosion. Nowhere else in the state is the seam more regular and persistent. Even here, however, it varies considerably and sometimes thins to such an extent that it is not of workable thickness. This is true in part at least of Somerset and Colerain townships. Probably over parts of the territory in which the map shows the seam present it will be found wanting or of unworkable thickness. This condition results from the fact that over considerable areas the seam is below drainage and has not been mined, making accurate measurements of the coal impossible.

The seam lies from 60 to 100 feet above the Pittsburg coal and hence the two are found beneath nearly the same territory. The Pittsburg coal, however, is the thicker seam and is of superior quality. This fact will keep the Meigs Creek coal in place until the lower seam shows signs of exhaustion.

Flushing Township. This township is remarkable for having at the present time the one mine for railroad shipment of the Meigs Creek coal in Ohio. Shipment by rail is said to have begun as early as 1880. Mining is done by machinery, and the coal is hauled from the mine by electrical power.

The mine is located at the village Flushing and is operated by the Flushing Coal Company. Section 36 was taken in this mine.

SECTION 36

	Ft.	In.
3. Soapstone,	1	4
2. Coal,	3	10
1. Sandstone, unmeasured,		

PLATE IV. Exterior Works of Flushing Coal Co., Flushing, Belmont Co. This is the only mine in Ohio from which the Meigs Creek Coal is shipped by rail.

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The seam is known locally as the Four foot coal, but it does not average quite that thickness. Probably 3 feet 8 inches is nearer the correct measurement. Nodules of pyrites are common in the coal, and have to be thrown out by the miners. The fuel makes a hot fire but is high in ash—a condition that will retard its development.

Chemical analysis and calorific value of Section 36:

Ultimate.		*Proximate.*	
Carbon	66.31	Moisture	4.98(a)
Hydrogen	4.95	Volatile Matter	33.30
Oxygen	12.32	Fixed carbon	48.90
Nitrogen	1.19	Ash	12.82
Sulphur	2.41		
Ash	12.82		
	100.00		100.00

Calorific value.....6652 calories.

(a) Moisture in the air-dried sample about 2%.

The sample included all of part 2 of the above section except about one inch of impure coal near the top. The sample measured about 5 inches in width and 2 inches in depth.

Among the places in this township where the coal has been worked in a small way by farmers may be mentioned: Northwest quarter, section 19, Joseph Bailey farm; Southwest quarter, section 25, Mahlon T. White farm; Northeast quarter, section 31, A. McElwain farm; Southeast quarter, section 33, L. M. Dunlap farm; Northwest quarter, section 27, Wilson farm; Southwest quarter, section 21, A. Barricklow farm; Northwest quarter, section 13, T. Conrow farm.

The average of the Meigs Creek coal in this township is small being in fact almost restricted to the high lands in the extreme eastern part which constitute the divide between the waters flowing into the Ohio and Muskingum Rivers.

The interval between the Pittsburg and Meigs Creek coals in this township varies considerably ranging from about 65 to 90 feet.

The hilltops in the eastern part of the township contain a higher seam. It lies from 100 to 110 feet above the Meigs Creek coal, but is nowhere worked. At Flushing this seam measures approximately two feet in thickness.

Wheeling Township. The Meigs Creek coal is found wherever due in this township. Near the western border the seam is just above drainage, but eastward it has been more extensively removed, the large streams deepening their channels more rapidly than the coal dips.

The seam has been worked in a small way at a number of places, but nowhere for railroad shipment. On the McCracken farm, northeast quarter section 20, the coal was found as shown in Section 36a.

According to the proprietor, the interval between the Pittsburg and Meigs Creek seams, as shown by the drill, is here 80 feet.

Chemical and calorific value of Section 36a:

Ultimate.		*Proximate.*	
Carbon	66.41	Moisture	7.52(a)(b)
Hydrogen	5.14	Volatile Matter	31.75
Oxygen	13.99	Fixed carbon	49.19
Nitrogen	1.11	Ash	11.24
Sulphur	2.11		
Ash	11.24		
	100.00		100.00

Calorific value.....6589 calories.

(a) Sample wet. Moisture probably 2% or 3% high on this account.

(b) Moisture in the air-dried sample about 2%.

The sample included the whole of the section except 7 inches at the bottom, which could not be reached on account of water standing in the mine.

The seam has also been worked on the Branson farm, northwest quarter, section 8; on the Beall and Lyell farms, southwest quarter, section 2; on the Caldwell farm, southeast quarter, section 1; on the Ritchey farm, southeast quarter, section 7; on the Grimes farm, southwest quarter, section 7; on the Walker farm, southwest quarter, section 3, and on the McCracken farm, northeast quarter of section 20.

In quality and thickness the coal is similar to the corresponding seam in Flushing township. The development of the Meigs Creek coal is retarded by the larger and better one, the Pittsburg or No. 8 coal, which is exposed along all the deeper valleys of the township.

The higher coal also is found in the hilltops over the entire township. Its place is about 100 feet above the Meigs Creek seam, but it is nowhere worked. The lower seams—Meigs Creek and Pittsburg—must be removed before this hilltop seam will become valuable.

Colerain Township. The Meigs Creek coal in this township is cut out in the deep valley of Wheeling Creek and along its principal tributaries. Elsewhere it is under cover except in the northeast corner where it is cut out along a stream in sections 9 and 15. The coal is thinner in this township than farther west. At Barton Station it measures 2 feet 3 inches. Eastward from this place it is still less important, and is probably nowhere of workable thickness. The seam is not mined anywhere in the township, though it is reported to have been formerly worked at Barton Station.

The following section was measured at Barton Station by Mr. J. E. Hyde:

	Ft.	In.
Shales with a few thin layers of sandstone	25	0
Uniontown coal	3	0

	Ft.	In.
Unseen	45	0
Sandstone, thin bedded	13	0
Limestone	10	8
Shales	3	0
Unseen	7	4
Limestone	3	0
Unseen	12	6
Shaly sandstone	3	5
Limestone and shales	19	2
Limestone	13	2
Limestone and shales	20	1
Shales	1	10
Meigs Creek coal	2	3
Shaly sandstone	5	2
Black shale	0	2
Coal	0	8
Shales and very thin limestone layers	4	0
Shales	5	2
Unseen	5	0
Limestone and shales	41	4
Unseen	25	0

Pittsburg coal, unmeasured.

While the Meigs Creek coal diminishes in importance in this township, the higher seams become more valuable. The Unointown coal lies from 110-145 feet above the Meigs Creek, and is known locally as the "Three-Foot seam." It is worked in a very small way at a number of places, among which may be mentioned the Wise farm, northeast quarter of section 20. Another place is near the school house in the southwest quarter of the same section. The seam there measures 4 feet.

Lying about 100 feet higher than the Uniontown coal is found another seam in the hill tops of the eastern part of the township. This coal is sometimes called by the farmers, "The Upper Six-foot seam" and sometimes the "Cut seam" from its exposure in the cut on the Colerain pike at the top of the hill back of Martin's Ferry. The coal has been worked at Colerain, just below the greenhouse. It is of poor quality.

The Pittsburg coal underlies the township except where cut out by Wheeling Creek and to a small extent by its tributaries. It is extensively worked and is of great value.

Pease Township. The thinning of the Meigs Creek coal noted in Colerain township to the west, continues in Pease township where it is represented by a thin stratum two or three inches in thickness or wanting entirely, its place being taken by dark shales. It is not mined anywhere in the township.

The Uniontown or "Three-foot Seam" is mined at a number of places, among them the Helsey and Thomas farms in the southeast quarter of section 36, and the old Woods farm in the northeast quarter of section 35. On the latter farm a seam 2½ feet in thickness is found 40

feet below the Uniontown coal, and the same is true two miles farther north, only the interval there is smaller, being about 25 feet. and the lower coal much thinner.

The highest seam of all, known locally as the "Upper Six-foot" or "Cut seam," is found in the hill tops over the township. As previously stated it is of poor quality, a layer or two only near the top being good. The coal has been mined on the Owen Carr farm in the southeast quarter of section 35 where it is reported 6 feet in thickness. In the cut on the Colerain pike back of Martin's Ferry the seam measures 6 feet 5 inches.

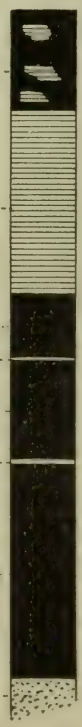
The Pittsburg coal underlies the township except where removed by erosion. It has long been mined on the river front for use in Martin's Ferry and Bridgeport. Occasionally it is hauled over trestles directly from the mines in the hill side to the large steel works, thus reducing the cost of fuel to a minimum.

Warren Township. The Meigs Creek coal underlies a large area in the southeastern part of Warren township. Elsewhere in the township the seam has been largely removed by stream erosion, and as a result is now found only in the ridges between the streams. In a few places the coal extends over the line into Guernsey county, but not in sufficient quantity to be of commercial importance.

The coal has long been mined in the vicinity of Barnesville where it is sometimes known as the Upper Barnesville seam. Section 37 was measured in the Malden mine, Barnesville.

SECTION 37

	Ft.	In.
8. Roof coal, (shale and coal,)	1	0
7. Shale and soapstone,	1	10
6. Coal,	0	7 ½
5. Pyrites parting,		1/16
4. Coal,	0	11 ½
3. Black shale,	0	¼
2. Coal,	2	1 ½
1. Soapstone, unmeasured,		



The seam in this bank ranges from 3 feet 8 inches to 4 feet 3 inches in thickness. Thin partings of shale or pyrites are common, but usually these are local. In other words, they are not persistent as in the Pittsburg seam. The coal is marketed in Barnesville where it is regarded as a fuel for grates.

Chemical analysis and calorific value of Section 37:

Ultimate.		*Proximate.*	
Carbon	65.83	Moisture	4.47(a)
Hydrogen	4.99	Volatile Matter	35.31
Oxygen	11.71	Fixed carbon	47.15
Nitrogen	1.13	Ash	13.07
Sulphur	3.27		
Ash	13.07		
	100.00		100.00

Calorific value.....6668 calories.

(a) Moisture in the air-dried sample about 2%.

Parts 1, 7 and 8 of the section were excluded in sampling. The sample measured 6 by 3 inches.

Here as elsewhere in the county the seam has the disadvantage of having to compete with the Pittsburg coal which is thicker and of superior quality. As long as this seam remains, the Meigs Creek coal will continue to be mined in the small way only.

Kirkwood Township. The Meigs Creek coal is found in the hills in the southern part of this township. The area, however, is small, and the seam nowhere worked.

Somerset Township. Nearly the whole of this township is underlain with the Meigs Creek coal. Very few exposures of the seam are found, however, owing to its being so generally below drainage.

In the extreme northeast corner of the township, on the Starbuck farm, section 6, a bank was opened a few years ago. The writer was not able to enter the mine, but learned that the coal measures about 4 feet in thickness.

On the western side of the township the coal has been mined near Temperanceville on the Austin Gallaher farm in section 33. The seam is reported to be 2½ feet thick and to contain many impurities.

The coal has been mined in a very small way at a number of places in the southwestern corner of the township, especially along the stream which heads near Boston (Atlas P. O.) and flows southwest into Monroe county. On the Shuman farm, northwest quarter, section 25, the following section of the coal was furnished by the proprietor:

	Ft.	In.
Soapstone	0	6
Coal	1	6
Soapstone	0	2
Coal	0	10

The coal is reported to vary in this locality from 2½ to 4 feet in thickness, and to be very impure.

In the valley of Captina Creek at Somerton several test wells for coal have been drilled. One found the Meigs Creek coal at a reported depth of 90 feet and another at 93 feet. The seam is said to be about 4 feet in thickness. The Pittsburg or No. 8 seam lies about 72 feet below the Meigs Creek, and is reported to be 4 feet 10 inches thick.

A higher coal known as the "Hill or Three-foot seam" has been mined at a number of places in the southern part of this township. On the Yocum farm, just south of Somerton, this coal formerly supplied the village grist mill with fuel. The mine is said to have been abandoned because of trouble from water.

Usually this seam is less than 3 feet in thickness and sometimes almost disappears. It is of poor quality.

Practically speaking this entire township is underlaid with the Pittsburg coal which as yet has scarcely been touched. The same is almost equally true of the next higher seam, the Meigs Creek. The "Hill or Three-foot" seam is smaller in area and otherwise inferior. Obviously this township contains a very large quantity of fuel.

Union Township. The Meigs Creek coal underlies the greater part of this township. In the deep valleys in the western and northeastern parts, however, the coal has been removed.

While the coal is not mined in the large way anywhere in the township, it is opened at several places by farmers who rely on it in part for their fuel.

Section 38 represents the coal in the mine of William Lodge at Lafferty.

Chemical analysis and calorific value of Section 38:

Ultimate.		*Proximate.*	
Carbon	68.32	Moisture	4.31(a)
Hydrogen	5.09	Volatile Matter	32.47
Oxygen	11.86	Fixed carbon	51.54
Nitrogen	1.11	Ash	11.68
Sulphur	1.94		
Ash	11.68		
	100.00		100.00

Calorific value.....6837 calories.

(a) Moisture in the air-dried sample about 2%.

The sample included the entire section except parts 1, 7 and 8.

In the mine of J. S. Calbert in the southeast quarter of section 25 the coal was found as shown in Section 39.

The coal is quite irregular in thickness. Occasionally it is much reduced by "horse backs" of sandstone and at other times by broad

SECTION 38

	Ft.	In.
8. Impure coal,	0	4
7. Soapstone,	1	3
6. Coal,	1	1 ½
5. Parting,		⅜
4. Coal,	1	2 ½
3. Parting,	0	¼
2. Coal,	1	9 ½
1. Clay,		

SECTION 39

	Ft.	In.
7. Soapstone,	1	6
6. Pyrites,	0	⅛
5. Bone coal,	0	2
4. Coal,	0	7
3. Pyrites,	0	¼
2. Coal,	3	9
1. Shale, unmeasured,		

rolls in the floor. The position of the roof too, shows sudden changes, often varying several inches in 2 or 3 feet.

The coal is hard and bright but with occasional streaks of bone coal and shale, the latter of paper like thinness. It is unusually free from pyrites layers or nodules. This mine supplies in part the surrounding country and also the mills at Morristown, Belmont and Bethesda.

Chemical analysis and calorific value of Section 39:

Ultimate.		*Proximate.*	
Carbon	69.90	Moisture	4.17(a)
Hydrogen	4.97	Volatile Matter	35.09
Oxygen	11.33	Fixed carbon	51.14
Nitrogen	1.09	Ash	9.60
Sulphur	3.11		
Ash	9.60		
	100.00		100.00

Calorific value.....7001 calories.

(a) Moisture in the air-dried sample about 2%.

The sample included parts 2, 3 and 4 of the section, and was cut from a face less than a day old. The sample measured 4 by 2 inches.

The Meigs Creek coal is mined on the John Gilliam farm in the southwest quarter of section 22, and also on the William Dunbar farm in the northwest quarter of section 6. The following measurement of the seam was made in the Dunbar mine:

	Ft.	In.
Shale	0	6
Soapstone	1	8
Coal	0	9
Soft shale	0	½
Coal	4	1

Shale, unmeasured.

The coal is quite free from impurities. The soapstone above the coal is taken down in the rooms leaving the shale to form the roof. It serves this purpose well. In the entries the soapstone is not usually removed.

The Pittsburg or No. 8 coal underlies practically the entire township. It is worked in a small way at a number of places in the western part of the township where the coal outcrops and is the principal reliance of the citizens for fuel. The interval between the Meigs Creek and Pittsburg seams in the vicinity of Morristown is about 85 feet.

In the southeastern part of the township two seams higher than the Meigs Creek are found. Both are occasionally worked on a small scale by the farmers. On the J. W. Bentley farm in the southeastern corner of section 1, the lower of the two higher seams referred to has been mined by stripping in the bed of the creek. The exposure did not admit of measurement when visited by the writer, but the proprietor reported the thickness to vary from 2 to 3½ feet with an average of about

3 feet. This seam is reported, on evidence of a deep well, to lie about 190 feet above the Pittsburg coal, and approximately 100 feet above the Meigs Creek seam.

On the J. P. Owens farm, which joins the Ramsey referred to in the preceding paragraph, a seam is mined that lies about 50 feet higher than the one stripped on the Ramsey farm. This seam is small and unimportant.

Richland Township. This, the largest township in the county, contains a great quantity of mineral wealth.

Th Meigs Creek coal outcrops in valleys in the northern and southeastern parts of the township, but is elsewhere deeply buried. In the northwestern part of the township the seam has been worked on the Mitchener Heirs and George farms, both in section 12. The seam has also been mined in the bed of the creek in sections 12 and 18.

Along Wheeling Creek and tributaries in the northeastern part of the township the coal outcrops, but little attention is paid to it owing to the presence of the Pittsburg seam.

In the southeastern part of the township the coal outcrops in the valleys traversed by the Baltimore and Ohio railroad, and the St. Clairsville branch of this road. The seam has been mined on the Cunningham farm in the southeast quarter of section 32. It is now worked in a small way at several places between Neff's Station and Glencoe. The seam is finely shown in the railroad cut at Glencoe, being there about 4 feet thick and approximately 85 feet above the Pittsburg coal.

A higher seam than the Meigs Creek is worked in a very small way at a number of places in the township, especially in the hilltops near St. Clairsville. The seam is thin and at present of little value.

The Pittsburg coal underlies practically the entire township, being in fact removed by erosion only along Wheeling Creek in the extreme northeast corner of the township.

Pultney Township. The Meigs Creek coal underlies a large part of this township. It has been removed in the valley of McMahon's Creek and its principal tributaries, and of course in the valley of the Ohio River.

The coal has been mined in the hills facing the river just south of Bellaire. It is now mined on Brook's Run in the southeast corner of section 5 where it measures about 4 feet in thickness and is only 65 feet above the Pittsburg seam. The coal is mined also on the Giffen farm in the northeast quarter of section 7.

No extensive development of the Meigs Creek coal in this township needs be expected as long as large areas of the Pittsburg seam remain.

Goshen Township. The Meigs Creek coal underlies the whole of this township except along the streams in the northwest and southwest corners. Mines have been opened on several farms in the former area, but these have nearly all been abandoned.

At the Statler mine in the southeast quarter of section 31, the coal was found as shown in Section 40.

SECTION 40

	Ft.	In.
6. Soapstone,		
5. Bone coal,	0	1
4. Coal,	2	7½
3. Shale, and coal,	0	4
2. Coal,	1	5
1. Sandstone,		

Sometimes the seam measures 5 feet in thickness. Occasionally it disappears entirely, the soapstone roof cutting out the coal. It contains considerable iron pyrites.

Chemical analysis and calorific value of Section 40:

Ultimate.		*Proximate.*	
Carbon	64.77	Moisture	3.40(a)
Hydrogen	4.86	Volatile Matter	35.72
Oxygen	9.96	Fixed carbon	45.94
Nitrogen	1.08	Ash	14.94
Sulphur	4.39		
Ash	14.94		
	100.00		100.00

Calorific value.....6578 calories.

(a) Moisture in the air-dried sample about 2%.

The sample included parts 2 and 4 of the above section, and was cut from a dry face that had been exposed less than two weeks. The sample measured 6 by 4 inches.

Near Belmont a higher seam is occasionally mined by the farmers, the coal being known as the Belmont. It is doubtless to be correlated with one of the higher seams mentioned in the discussion of Union township, which joins Goshen on the north.

Smith Township. The Meigs Creek coal is everywhere below drainage in the township except in the northeast part where it is cut out by

McMahon's Creek and one of its tributaries. On the land of Rev. Thomas H. Armstrong the coal was found as represented in Section 41.

SECTION 41

	Ft.	In.
8. Shale,		
7. Coal, not mined,	0	6
6. Coal,	1	9½
5. Shale,	0	⅜
4. Coal,	0	6
3. Shale,	0	¼
2. Coal,	1	0
1. Coal with pyrites,	0	½

The coal varies considerably in thickness owing to rolls in the floor. Numerous thin layers of shale and pyrites are found. These are not continuous but appear and disappear with frequency. The coal has a market among the surrounding farmers and in the village Glencoe.

Chemical analysis and calorific value of Section 41:

Ultimate.		*Proximate.*	
Carbon	67.36	Moisture	3.52(a)
Hydrogen	5.02	Volatile Matter	34.74
Oxygen	11.06	Fixed carbon	49.90
Nitrogen	1.05	Ash	11.84
Sulphur	3.67		
Ash	11.84		
	100.00		100.00

Calorific value.....6884 calories.

(a) Moisture in the air-dried sample about 2%.

This sample included the whole of the above section except parts 1 and 8. The face from which the sample was cut, except part 7, had been exposed only a day or two. Part 7 had been exposed perhaps three months, but did not appear weathered in any way.

Mead Township. The Meigs Creek coal underlies the whole of this township except the eastern part where it is cut out by the Ohio River and several of its tributaries.

The seam has been mined by farmers in the valley of Pipe Creek as far up as Businessburg, just beyond which the coal goes under cover. The seam would be more largely worked in this vicinity were it not for the competition of the Pittsburg coal which is mined on the Berry farm

in the southeast quarter of section 18, and also at Dille's Bottom where Pipe Creek empties into the Ohio River. The Pittsburg seam is said to lie in the bed of the river at this place.

The Meigs Creek coal is exposed in the valley of Wegee Creek as far as the middle of section 2 where the seam goes under cover. The following section of the coal was made in this valley at the McMillen bank in the northwest quarter of section 32:

	Ft.	In.
Soapstone	3	0
Roof coal, not mined	0	4
Coal	4	5
Shales, unmeasured.		

No regular shale or clay partings are found in the coal, but irregular streaks of this material occur. The mine is worked on a small scale only.

A higher seam is mined on the Reiff farm in the southwest quarter of section 19. Its thickness is reported to vary from 18 inches to 3 feet. This seam lies about 160 feet above the Meigs Creek coal.

Wayne Township. The Meigs Creek coal is exposed in the valley of Captina Creek and its principal tributaries as far east as the Evans farm in section 10. There it dips below the creek, reappearing in the valley of the same stream about two miles west of Armstrong's Mills.

In the northwest corner of the township the coal has been opened on a number of farms, and is reported about 4 feet thick. Farther down Captina Creek the coal has been stripped in the bed of the stream.

The Pittsburg coal is nowhere above drainage in this township. This condition favors the mining of the Meigs Creek coal, but notwithstanding this the quantity of mining done in this township is small. The farmers seem to prefer hauling their fuel from Barnesville or Armstrong's Mills to the trouble of keeping a mine in order.

Washington Township. The Meigs Creek coal is below drainage in the western part of the township. It appears in the bed of Captina Creek on the Danford farm, near the junction of sections 16 and 22, and is above drainage farther down the valley.

The coal is reported to have been mined for half a century in a small way in the vicinity of Armstrong's Mills. Below is a section of the Hoover mine at that place. The section was furnished by the proprietor, the mine not being in a condition to be entered:

	Ft.	In.
Soapstone	1	4
Coal	1	8
Soft shales	0	2
Coal	1	8
Shales, unmeasured.		

The seam is said to average about 3½ feet in thickness in this locality, the extremes given being 2 and 4½ feet. Occasionally the roof dips causing a thinning of the seam.

The Pittsburg coal is mined for local use and railroad shipment at Armstrong's Mills. The seam is reached by a shaft the distance to the bottom of the coal being 69 feet.

On the hills along the western line of the township a higher seam appears. It is occasionally mined by farmers.

York Township. The Meigs Creek coal has been more extensively removed by erosion in this township than elsewhere in the southern part of the county. The seam outcrops in the valley of Captina Creek and its tributaries, and of course in the valley of the Ohio River.

Usually in the valley of Captina the coal lies a few feet only above drainage, but near Steinersville in the eastern part of the township, a marked anticline exists which brings the Pittsburg seam up to or slightly above water level. Here the Meigs Creek coal is well above drainage. This seam is now worked on the Korner farm in the northwest quarter of section 8.

The coal was formerly mined on the Ramsey farm at the west edge of Powhatton. It is found in the bed of the Ohio River about one and one-half miles south of the Belmont county line, where it has occasionally been mined by stripping during low water stages.

In the northeast corner of the township the coal is well shown along a railroad cut in the hills facing the river. About 15 feet below it another seam exists. The latter is about 4 feet in thickness, but of poor quality.

The Pittsburg coal is mined in a small way on the Schnegg farm in the northwest quarter of section 19. Formerly this coal was mined on the Owing and Ring farms in the southwest quarter of section 14. It has also been stripped in the bed of Captina Creek near the middle of the township.

THE MEIGS CREEK COAL IN JEFFERSON COUNTY.

This coal is nowhere mined in Jefferson county. It is doubtful if the seam is of workable thickness anywhere in the county. If so it is in Mt. Pleasant township into which the seam may extend from Short Creek township, Harrison county on the west and from Colerain township, Belmont county on the south. As stated elsewhere, however, the seam thins in Colerain township and hence the extension from that locality is unimportant. The coal is thicker in Short Creek township and probably extends into the western part of Mt. Pleasant township as a workable seam. No measurement of the seam was made for the reason that no suitable exposure of the coal was found.

The report on this seam elsewhere in the county is still less favorable. In Warren township, lying east of Mt. Pleasant, the seam is due, but is represented by a black streak only. Much the same condition prevails in Smithfield, Wells, Cross Creek and Wayne townships. In

none of these does the Meigs Creek coal exceed a few inches in thickness, and often it is represented by a thin streak and occasionally even that may be wanting.

THE MEIGS CREEK COAL IN NOBLE COUNTY.

The Meigs Creek coal is found in every township in the county with the possible exception of Buffalo. Duck Creek which crosses the county north to south in a deep and rather wide valley divides the coal into two areas, an eastern and western one.

The coal area west of Duck Creek is extensive, usually lies low in the hills and is exposed for the most part in the deeper valleys only. East of Duck Creek the coal lies high in the hills and hence is found beneath a relatively small part of the territory.

Nowhere is the coal mined for railroad shipment, but it is worked at many places for a local market. The supply for this purpose is adequate and will last for an indefinite period.

This seam was mapped and studied by Professor C. N. Brown and his report may be found in Volume V., Geological Survey of Ohio, published in 1884. Conditions in the territory have not changed materially since that report appeared, but since it is now out of print it is deemed advisable to review the essential facts here.

Beaver Township. This lies in the extreme northeastern corner of the county. The place of the coal is high in the hills and hence it is due in only a relatively small part of the township. It is not, however, always present in workable thickness where due. Thus in the southeastern quarter of the township the coal does not appear to be anywhere of mining thickness, but farther west the seam is an important source of fuel for the farmers.

In the southeast quarter of section 17 Professor Brown found the coal as follows:[1]

	Ft.	In.
Sandstone, massive.		
Shales	1	6
Coal	1	4
Clay	1	4
Shales	0	2
Coal	2	6
Clay	0	2
Coal	2	0
Clay	2	0
Limestone, unmeasured.		

Sections taken elsewhere in the township show a similar structure and thickness. Obviously one of the disadvantages of this seam is the numerous partings which make the coal dirty and increase the expense of mining.

The Pittsburg or No. 8 coal is at present mined in sections 5 and 11.

[1] Vol. V., p. 1082.

It appears to be present where due in workable thickness in the northeast quarter of the township, but farther west and south is wanting. The limestones lying below the coal are present, serving to locate the place of the seam.

Marion Township. This township lies south of Beaver. Its topography is very rough and the tops of the high ridges are well above the coal. Country banks are numerous, especially south and west of Summerfield. The coal mined, however, does not meet the demand, for much is hauled from the Stafford field in Elk township.

Section 42 was obtained in a mine on the C. T. Hague farm in the southeast quarter of section 12, about one and one-half miles northwest of Summerfield.

SECTION 42

	Ft.	In.
7. Coal,	0	9 ¼
6. Shale,	0	¼
5. Coal,	1	11
4. Shaly pyrites,	0	¼
3. Coal with 3 pyrites streaks,	1	1
2. Coal,	0	2
1. Coal, impure not mined,	0	6

In thickness the coal varies from 4 feet 3 inches to 4 feet 9 inches. Overlying the coal is a bed of soapstone whose thickness is reported to range from 8 to 16 inches. Above the soapstone is the roof coal whose thickness is said to vary from 8 to 12 inches. Rarely is it wanting. The roof is quite strong, permitting the shooting of the coal. Concretions of pyrites are abundant near the base of the coal but less common higher in the seam.

Chemical analysis and calorific value of Section 42:

Ultimate.		*Proximate.*	
Carbon	65.61	Moisture	3.12(a)
Hydrogen	5.09	Volatile Matter	37.36
Oxygen	9.93	Fixed carbon	46.67
Nitrogen	0.92	Ash	12.85
Sulphur	5.60		
Ash	12.85		
	100.00		100.00

Calorific value.....6739 calories.

(a) Moisture in the air-dried sample about 2%.

The sample included the entire section except parts 1 and 2, and measured 3 by 1½ inches. It was cut from a face that had been exposed about two weeks.

Sections taken elsewhere in the township show the same general structure, though the individual members vary in thickness.

In the ridge extending north from Summerfield the coal is thin or wanting.

Stock Township. The East Fork of Duck Creek crosses this township in almost a diagonal way in a deep narrow valley along which and its tributaries the Meigs Creek coal is exposed and frequently mined. It lies well up in the hills.

The coal ranges in thickness from 3½ to 5 feet with perhaps an average of 4 feet.

Section 43 was taken on the farm of Uriah Cleary, northwest quarter section 25.

SECTION 43

	Ft.	In.
7. Soapstone, unmeasured,		
6. Coal, with 2 thin partings of pyrites,	0	9½
5. Parting, Smut band,	0	⅛
Coal,	0	⅜
Smut band,	0	⅜
4. Coal with a thin layer of pyrites,	1	7
3. Bone coal, rejected,	0	1¼
2. Coal,	1	3½
1. Coal, impure,	0	3

This mine has been in operation several years, the output being consumed by farmers and neighboring villages. The coal is quite hard and averages about 4 feet in thickness with a maximum of 5 feet. Rolls in the floor are not uncommon and where present reduce the thickness of the seam. Pyrites concretions from one to four inches in thickness and sometimes 3 feet in length are abundant.

Overlying the coal is a bed of soapstone reported to vary from 1½ to 2 feet in thickness, and above this the roof coal which is said to range from 2 to 2½ feet and to be more shaly than the coal below.

Chemical analysis and calorific value of Section 43:

Ultimate.		*Proximate.*	
Carbon	67.50	Moisture	2.55(a)
Hydrogen	5.11	Volatile Matter	38.40
Oxygen	9.27	Fixed carbon	47.64
Nitrogen	0.92	Ash	11.41
Sulphur	5.79		
Ash	11.41		
	100.00		100.00

Calorific value ..... 6,952 calories.

(a) Moisture in the air-dried sample about 2%.

The sample included the entire section except parts 1, 3 and 7, and measured 3 by 1½ inches. It was cut from a face that had been exposed less than one day, but was not over 50 feet from the outcrop.

While the township will probably never be a large shipper of coal, it contains an adequate supply for home consumption.

Elk Township. The topography of this township is similar to that of Stock. East Fork of Duck Creek crosses the county in a broad curve from the northwest to the southwest, along which the coal is everywhere exposed.

The coal lies lower in the hills than farther north and west and hence has been less removed by erosion.

In the southeastern part of the township, section 13, Professor Brown found the coal as follows:

	Ft.	In.
Hard shale, unmeasured.		
Coal	2	6
Clay	1	0
Coal	1	2
Bone coal	0	4
Coal	1	1
Shale parting	0	½
Coal	1	6
Clay	2-4	0
Limestone	16	0
Shaly sandstone, unmeasured.		

In the northeastern corner of the township the coal is at its best and, for country banks, is quite extensively mined. The mines are known as the Stafford from the village across the line in Monroe county.

Coal is hauled long distances from this place. Graysville, Jackson Ridge, Rhinards Mills and other villages look to it for a supply.

The roof of the coal varies much. Numerous "rolls" or "horses" cut out the coal partly or entirely. Usually these breaks are narrow, from 10 to 12 inches, and have steep or vertical sides as if they had been deposited in narrow canyon like valleys cut in the coal. The "rolls" or "horses" are composed of soapstone with pyrite nodules.

Section 44 was measured on the G. W. Love farm on Snaler Run in the northern part of the township.

SECTION 44

	Ft.	In.
4. Coal,	1	8
3. Shaly pyrites,	0	¼
2. Coal with smut bands near top,	3	2
1. Pyrites layer,	0	⅛

Directly overlying the main body of the coal is a bed of soapstone usually about 6 inches in thickness, but occasionally increasing to 2 feet. Above this is the roof coal, reported 2½ feet in thickness, the whole making a good cover.

Chemical analysis and calorific value of Section 44:

Ultimate.		*Proximate.*	
Carbon	66.18	Moisture	3.06(a)
Hydrogen	5.11	Volatile Matter	38.43
Oxygen	9.52	Fixed carbon	46.18
Nitrogen	0.86	Ash	12.33
Sulphur	6.00		
Ash	12.33		
	100.00		100.00

Calorific value ..... 6,865 calories.

(a) Moisture in the air-dried sample about 2%.

The sample was cut from the whole section, except part 1 which was rejected. The sample measured 3 by 2 inches, and was cut from a face that had been exposed about two weeks, but which appeared thoroughly fresh.

Jefferson Township. This township lies west of Elk which it resembles in geological conditions. The Middle Fork of Duck Creek crosses the eastern side of the township in a deep valley and its numerous tributaries also have cut through the coal. On the western side of the

township the streams after a short journey drain into Duck Creek. All in all, the township must be rated with the roughest in the state.

While the township contains a large acreage of the Meigs Creek coal, it lies well up in the ridges and hence has been extensively eroded. The supply, however, is adequate for local demands.

Enoch Township. The coal in this township lies higher in the hills than in Jefferson since the township in question is farther west. The coal has been largely removed by erosion.

Section 45 was secured on land of Mrs. Catherine A. Dillehay, one mile north of Dexter City.

SECTION 45

	Ft.	In.
6. Coal,	0	3½
5. Shale,	0	¼
4. Coal with 2 pyrites lamella	1	6
3. Tough streak consisting of coal, pyrites, shale and smut rock,	0	9½
2. Coal with 2 thin pyrites bands,	1	4¾
1. Coal in floor	0	2½

The section represents the Lower bench of the seam only. The Upper bench is not mined. It is reported about as thick as the Lower bench, but of poor quality. The mine supplies neighboring farmers, oil men and in part Dexter City.

Chemical analysis and calorific value of Section 45:

Ultimate.		*Proximate.*	
Carbon	68.53	Moisture	2.90(a)(b)
Hydrogen	5.22	Volatile Matter	37.24
Oxygen	10.78	Fixed carbon	49.70
Nitrogen	1.04	Ash	10.16
Sulphur	4.27		
Ash	10.16		
	100.00		100.00

Calorific value ..... 7,051 calories.

(a) Sample was very wet when cut and was dried in the sun for half an hour before putting into the can for shipment. Moisture probably in the neighborhood of 1% lower tnan as mined on this account.

(b) Moisture in the air-dried sample about 2%.

The sample was cut from the whole section, except parts 1 and 3 which were rejected. The lower part of the section was wet, and the sample was dried in the sun a half hour before sealing.

Part 3 of the section was sampled separately and gave the following results:

Ash	18.63
Sulphur	3.89

Country mines are found at many places, especially along Buffalo Run in the extreme southern part of the township and near the village Fuldah in the northeastern part. Formerly the coal was mined for railroad shipment in section 31 in the southwestern corner, but this work has long been abandoned. In thickness the coal is at its best in the southern part; farther north it thins and grows of less value.

Center Township. Here the coal is restricted to high narrow ridges and isolated hills. In the northwestern corner even these are too low for the coal. Many country mines are found in the township, particularly the southeastern part. The coal is fairly steady in thickness and averages about 4 feet. The supply is adequate for local use but not for railroad shipment.

Seneca Township. The area of the Meigs Creek coal in this township is small, being restricted to a few high hills or ridges. Near the hamlet of Mt. Ephraim, Professor Brown found the coal as follows:

Hard shale, unmeasured.	Ft.	In.
Bone coal	1	4
Coal	0	8
Clay shale	1	0
Coal	0	10
Parting	0	1
Coal	1	3
Parting	0	1½
Coal	1	8
Clay, unmeasured.		

The several members of this section, especially the shales and partings vary in thickness from place to place. The coals are more steady.

Noble Township. The area of the Meigs Creek coal here is small and restricted to the hill tops of the eastern and southwestern parts of the township. The coal is usually from 4 to 4½ feet in thickness and in the southwestern part supplies a small number of farmers with fuel.

In section 13 Professor Brown found the coal 258 feet above the Ames limestone.

Olive Township. This township is crossed from north to south by Duck Creek which flows through a prominent valley. East of the valley the Meigs Creek coal is wanting except in three or four sections near

the Enoch township line. The area of coal here is of course very small. In section 13 Professor Brown found the coal 4 feet 9 inches thick, but divided into three parts by two impure layers.

West of Duck Creek the area of coal is much larger and more important as a local source of fuel. However it lies well up in the hills and has been extensively eroded. The coal is thickest to the south where it sometimes reaches 4 feet. In the northern part of the township the seam ranges from 2½ to 3½ feet, but the latter thickness is uncommon.

Brookfield Township. This township lies in the northwestern corner of the county. About one-half of it is underlain with the Meigs Creek coal. Exposures of the seam are numerous, especially in the northern part.

Section 46 was taken in a bank on the H. C. Hunter farm in the northwest quarter of section 4.

SECTION 46

		Ft.	In.
10.	Bone coal,	0	5½
9.	Shale,	0	¾
8.	Coal.	0	8½
7.	Shale parting with pyrites,	0	⅜
6.	Coal,	1	3½
5.	Tough streak, shale, coal, shale,	0	1½
4.	Coal, with 2 thin smut bands,	0	10½
3.	Pyrites, quite persistent,	⅛	
2.	Coal, hard,	0	4½
1.	Coal in floor, not mined,	0	9½

This mine was opened about 30 years ago and has been worked almost continuously since that time. The number of miners employed has ranged from one to ten. The coal is marketed to surrounding farmers and to the village Cumberland in Guernsey county.

While the coal has several partings, these are small and the seam may be regarded as forming a single bench which ranges ordinarily from 4 feet 4 inches in thickness to 5 feet. Of this the uppermost 5½ inches consist of bone coal and is rejected; and the lower part of the seam, varying from 4 to 8 inches in thickness and of good quality, is left in the mine owing to the large quantity of water that exists in the bottom of the coal. Hence the coal as mined ranges from 3½ to 4 feet in thickness. Occasionally the bone coal at the top of the seam is of good quality, thus increasing the thickness of workable fuel by that amount.

The nature of the roof in this part of the township is shown by the following section measured in an entry:

	Ft.	In.
Sandstone, not measured.		
Block coal, very impure	0	5½
Bone coal	0	5½
Main body of seam.		

Usually the bone coal forms the roof but in the entries this coal and the overlying shales must be removed in order that the fuel may be hauled from the mine.

Chemical analysis and calorific value of Section 46:

Ultimate.		*Proximate.*	
Carbon	66.01	Moisture	4.85(a)(b)
Hydrogen	5.26	Volatile Matter	37.28
Oxygen	12.35	Fixed carbon	48.05
Nitrogen	0.97	Ash	9.82
Sulphur	5.59		
Ash	9.82		
	100.00		100.00

Calorific value .....6,834 calories.

(a) Sample slightly wet. Moisture possibly 1% high on this acount.
(b) Moisture in the air-dried sample about 2%.

Parts 1, 5, 9 and 10 of the above section were rejected in sampling.

In the northwestern quarter of section 31 in the southwestern corner of the township, Professor Brown reports the coal as follows:

	Ft.	In.
Clay shale, roof poor.		
Coal	0	6
Clay parting with ferriferous sandstone	0	½
Coal	1	1
Hard shale with ferriferous sandstone	0	½
Coal	2	4
Clay, unmeasured.		

This section shows less than the maximum of coal which is sometimes reported to reach 5 feet.

On the farm of J. M. Pickenpaugh, northeast quarter of section 35, the coal was found as shown in Section 47.

The coal is quite hard and contains frequent layers of shale of paper thickness. At one point in the entry the soapstone and sandy shale above the coal is one foot 8 inches in thickness. Above this bed is about 3 inches of dark shale with considerable pyrites, and an inch of coal. The latter appears to be the remnant of the upper member of the seam as found in the southern and eastern parts of Noble county and along Duck Creek in Washington county.

SECTION 47

	Ft.	In.
4. Coal, with 2 shale partings,	0	10
3. Coal,	1	5
2. Tough streak, coal with numerous pyrites and shale partings,	0	3
1. Coal, with 3 shale, and 3 pyrites partings,	2	3

Chemical analysis and calorific value of Section 47:

Ultimate.		*Proximate.*	
Carbon	64.44	Moisture	3.54(a)
Hydrogen	5.12	Volatile Matter	37.41
Oxygen	10.12	Fixed carbon	45.82
Nitrogen	0.88	Ash	13.23
Sulphur	6.21		
Ash	13.23		
	100.00		100.00

Calorific value ..... 6,642 calories.

(a) Moisture in the air-dried sample about 2%.

The whole section except part 2 was included in the sample, and measured 3 by 2 inches. It was cut from a face that had been worked the preceding day and so was fresh.

Part 2 of the section was sampled separately and gave results as follows:

Ash	23.53
Sulphur	6.69

From 30 to 40 feet below the coal in the northern part of the township there lies a bed of sandstone that makes a good building stone. It is best seen in the court house at Cambridge.

Sharon Township. This township lies southeast of Brookfield and contains a large area of the Meigs Creek coal. The seam has been cut through by the principal streams, but probably one-half of the coal remains.

Professor Brown found the coal from 3 to 3½ feet thick in the

northern part of the township and from 4 to 4½ feet in the southern part. The roof is bad and hence requires careful timbering.

The following section of the coal was made in a bank on the L. C. Harper farm at the village Olive Green:

		Ft.	In.
Coal		1	7½
"Tough streak"	Shale	0	¼
	Coal	0	½
	Shale	0	½
Coal		1	10

The coal is very hard and impure. Clay veins are occasionally found, and balls and lenses of pyrites are common. Many lamellae of shale of paper thickness run through the seam.

At one place the coal measured 4 feet 4 inches in thickness, but on the opposite side of the entry it was reduced to 18 inches. In an old bank nearby, the coal was reported to average only 28 inches, the maximum being 36.

Jackson Township. This township which forms the southwestern corner of the county contains perhaps as much of the Meigs Creek coal as any other two townships in the county. In the northeastern corner the coal lies high in the hills and hence has been extensively eroded, but the seam dips to the southwest and in the opposite corner of the township is below drainage.

The coal is mined for the farmers' use at many places, and especially in the northwestern part of the township. From that locality the coal is hauled miles in all directions.

Professor Brown found the coal as follows in the section 12 in the northeastern corner of the township:[1]

	In.
Shale, unmeasured.	
Coal, poor	18-24
Clay	14-18
Coal	52½
Clay, unmeasured.	

The coal thickens to the west and in section 10 occasionally measures 6 feet. In section 8 in the northwestern corner of the township Professor Brown found the coal as follows:

	In.
Clay shale, poor roof.	
Coal	42-48
Clay	1- 3
Coal	4- 6
Clay, unmeasured.	

Southwest from this mine in section 19 the coal is thinner owing to a sandstone dipping down and apparently cutting out part of the coal. The seam here is usually less than 4 feet thick.

[1] Vol. V, p. 1077.

THE MEIGS CREEK COAL IN MORGAN COUNTY.

This county which is divided into two parts by the Muskingum River contains a large quantity of the Meigs Creek coal. The seam is found wherever due east of the river, and is nearly always of workable thickness. West of the river, however, the seam is thin and commonly entirely wanting. No mines exist in this part of the county but east of the river many are found.

Bloom Township. This is the northwesternmost township east of the river. The coal is small in area and is restricted to the highest ridges. Its thickness ranges from 3½ to 4½ feet with one well marked parting near the middle. Commonly the coal is underlain with nonfossiliferous limestone.

Morgan Township. This lies south of Bloom and like that township has the Meigs Creek coal in the highest ridges only. In the hills fronting on the river the coal is thin and of little value, but farther east it measures from 3 to 3½ feet with a parting of from 3 to 4 inches near the middle.

Along the river hills Professor Brown found the coal 250 feet above the Ames limestone. In the same place the Pittsburg coal is 168 feet above the limestone, making the interval between the two coal seams 82 feet.

Windsor Township. The coal in this township lies low in the hills and hence has been little removed by erosion. It follows from this that exposures of the seam are not common and hence our information concerning it is relatively meager.

In lot 75 in the northwestern corner of the township Professor Brown found the coal 3 feet thick with an irregular band of shale near the middle. The coal thickens slightly eastward and near the mouth of Meigs Creek measures from 3 to 3½ feet.

Bristol Township. This township lies east of Bloom and like that township, is bounded on the north by Muskingum county. The township has been extensively eroded by Meigs Creek and tributaries and exposures of the seam are numerous. The area of the coal is not large and is restricted to the higher ridges.

In a bank on the D. C. Lawrence farm, northeast quarter of section 21, the coal was found as shown in Section 48.

The roof in this bank is too weak to stand shooting. The coal is quite hard and contains many shale laminae of paper thickness.

SECTION 48

	Ft.	In.
8. Roof shale,		
7. Thin parting of coal,		
6. Shale, 1 to 2 inches,		
5. Coal,	1	7¼
4. Shale,	0	¼
3. Coal,	0	2¼
2. Shale,	0	1
1. Coal,	2	0

Chemical analysis and calorific value of Section 48:

Ultimate.		*Proximate.*	
Carbon	67.04	Moisture	5.05(a)(b)
Hydrogen	5.14	Volatile Mattter	37.83
Oxygen	12.26	Fixed carbon	46.75
Nitrogen	0.89	Ash	10.37
Sulphur	4.30		
Ash	10.37		
	100.00		100.00

Calorific value .....6,730 calories.

(a) Sample slightly wet. Moisture possibly a per cent. high on this account.
(b) Moisture in the air-dried sample about 2%.

The sample included parts 1, 3, 4 and 5 of the section and measured 3 by 1½ inches. The coal was badly stained owing to the light covering.

On the land of A. E. Smith in section 25 the coal was found as follows:

	Ft.	In.
Shale, unmeasured.		
Coal	0	10
Shale	1	3
Coal	2	3
Shale	0	1
Coal	2	3
Fire clay, unmeasured.		

This section shows the two benches and also a still higher layer of coal. The latter is not mined.

Sections taken in other parts of the township show similar thickness and structure, and so no further measurements will be given.

Manchester Township. The area of this township is small but the

quantity of coal is relatively large for the seam is low in the hills and hence has not been extensively eroded.

Several banks are found in the vicinity of Reinersville which furnish that village with fuel and also a large area of the surrounding country.

In the mine of Louis H. Grandstaff, southwest quarter of section 29, the coal was found as represented in Section 49.

SECTION 49

	Ft.	In.
9. Soapstone, reported thickness,	15	0
8. Coal, not mined,	0	8
7. Coal,	1	2
6. Pyrites parting,	0	⅛
5. Coal,	1	¼
4. Hard streak. coal with shale and pyrites,	0	4½
3. Coal,	1	0
2. Pyrites,	0	¼
1. Coal,	0	8½

Here as elsewhere the coal contains numerous paper like layers of shale. In places the coal is bright and sometimes iridescent and then is called peacock coal. Pyrites partings are numerous, varying from one-eighth of an inch or less to half an inch or more in thickness, and often of considerable horizontal extent. Sometimes a half-dozen or more of these partings may be found in a single section.

Chemical analysis and calorific value of Section 49:

Ultimate.		*Proximate.*	
Carbon	66.19	Moisture	4.07(a)
Hydrogen	5.10	Volatile Matter	37.61
Oxygen	12.11	Fixed carbon	47.66
Nitrogen	0.87	Ash	10.66
Sulphur	5.07		
Ash	10.66		
	100.00		100.00

Calorific value ..... 6,779 calories.

(a) Moisture in the air-dried sample about 2%.

The sample included the whole of the section except parts 8 and 9. It was a little wet, but nevertheless is believed to be a very fair sample.

Meigsville Township. The Meigs Creek coal is found everywhere in this township except where cut out by the larger and deeper streams. In the southern part of the township the coal varies usually from 3 to 3½ feet in thickness, and according to Professor Brown is a little irregular. Farther north the seam thickens and in the northeastern corner of the township is quite largely worked.

On the Walker farm in section 1 the coal is reported to have been mined during the past 40 years. This mine supplies quite a number of surrounding farmers and in part the village Unionville about two miles to the south. In the entry to this mine the coal was measured as follows:

	Ft.	In.
Shales, unmeasured.		
Roof coal	0	7
Shales	0	5
Coal	2	0
Shales	0	5
Coal	1	10
Fire clay, unmeasured.		

About 80 feet below this seam the Pittsburg or No. 8 coal is found. Its thickness usually varies from 18 to 24 inches. Approximately 25 feet above the Pittsburg coal is another small seam, usually from 12 to 20 inches thick. This is the Pomeroy or 8a coal.

About one-fourth of a mile up stream from the Walker mine the No. 8 coal and associated strata are seen in the bank of the creek with the following succession and approximate thicknesses:

	Ft.
Sandstone	10
Dark shales changing to light gray near the top	25
Pittsburg or No. 8 coal	1½
Brown shales	1½
Limestone	3
Sandstone	2
Bed of Dye's Fork.	

On the land of F. S. Murray, northeast quarter of section 1, the coal was found as shown in Section 50.

Chemical analysis and calorific value of Section 50:

Ultimate.		*Proximate.*	
Carbon	64.77	Moisture	5.13(a)
Hydrogen	5.06	Volatile Matter	36.07
Oxygen	12.67	Fixed carbon	47.06
Nitrogen	0.87	Ash	11.74
Sulphur	4.89		
Ash	11.74		
	100.00		100.00

Calorific value ..... 6,625 calories.

(a) Moisture in the air-dried sample about 2%.

SECTION 50

		Ft.	In.
10.	Soapstone, unmeasured,		
9.	Coal, usually about 5 inches,	0	1¾
8.	Shale,	0	¾
7.	Coal, smut streak near middle,	1	2
6.	Bone coal,	0	4
5.	Coal,	0	8
4.	Pyrites layer,	0	⅛
3.	Coal,	0	1
2.	Pyrites,	0	¼
1.	Coal,	1	1

Parts 6, 8 and 10 of the above section were rejected in sampling. The sample measured 3 by 1½ inches, and was cut from a face that had been exposed less than a week.

Center Township. This forms the southeastern corner of the county and contains a much larger area of the Meigs Creek coal than any other township in the county. The coal is everywhere exposed along the principal streams, Big and Little Olive Green Creeks and two or three smaller streams as well as the Muskingum River where it forms the southern boundary of the township.

In the southeast quarter of section 28 Professor Brown found the coal as follows:[1]

	Ft.	In.
Coal	0	6
Bone coal	0	3
Coal	2	0

The following measurement was made in a bank on land of J. F. Rodgers, southwest quarter of section 27, on Olive Green Creek about one and one-half miles above its mouth:

	Ft.	In.
Coal	1	6
Shales and pyrites	0	1
Coal	1	11

The coal is hard and bright and does not contain so many streaks of shale as are usually found in this seam. Likewise pyrites is less common.

According to Mr. J. O. Roberts, who has worked in several mines in this general locality, the coal is usually 3 feet 8 inches in thickness and sometimes reaches 4 feet 4 inches. Both floor and roof "roll" making variations in the thickness of the seam.

[1] Vol. V, p. 1068.

Throughout the township the coal has a similar structure, that is consists of two benches separated by a few inches of shales or an impure coal. Rarely does this parting attain a thickness of 6 inches.

In the southwest quarter of section 23 the two benches aggregate 40 inches with a 3 inch parting between. In the northern part of the township, southwest quarter of section 9, Professor Brown found the upper bench 13 inches and the lower one 30 inches in thickness, with a 4 inch parting of black shale between the two.[1]

From what has been said it is apparent that this township and others farther north contain a large quantity of the Meigs Creek coal. Thus far this has supplied a local market only and such will probably be true for many years. The time will come, however, when this coal will be sought for larger markets and then the valleys will be dotted with mining camps such as may be seen at the present time in other parts of the state.

THE MEIGS CREEK COAL IN MUSKINGUM COUNTY.

A considerable area of this coal is found in the highland in the southeastern corner of the county.

Meigs Township. This contains by far a larger quantity of this coal than any other township in the county. The township joins Brookfield of Noble on the east and Bristol of Morgan on the south, and the coal is similar to the same seam in those townships.

In the southeast quarter of section 8, Professor Brown found the coal 39 inches thick and divided into 3 nearly equal benches by shale partings.[2] In section 9 the coal is thicker and the same is true in section 26.

While the township cannot be a large producer of coal it does contain a supply adequate to the needs of its citizens for an indefinite period.

Rich Hill Township. This township lies north of Meigs and west of Spencer, the latter in Guernsey county. A high ridge crosses this township from north to south with a uniting ridge from the east. These ridges contain about all of the seam that is found in this township. The coal is about 50 inches thick but often contains considerable impurities.

Besides the areas named a little coal is found in Blue Rock and Union townships. In Blue Rock the coal is restricted to the highest ridges and the quantity small, while in Union about all that can be said is that the coal is present at two or three points.

[1] Vol. V, p. 1068.
[2] Vol. V, p. 1070.

THE MEIGS CREEK COAL IN GUERNSEY COUNTY.

The area of this coal in Guernsey county is very small, being practically restricted to a part of Spencer township in the southwestern corner of the county. Just north of the village Cumberland is a high ridge which extends west into Muskingum county. In this the coal is found near the top of the ridge. The coal is mined in a small way, the structure and thickness being similar to that in Noble county.

THE MEIGS CREEK COAL IN MONROE COUNTY.

Monroe county contains less coal above drainage than any other county in southeastern Ohio. While two seams—the Pittsburg and Meigs Creek—are mined, the production of the two combined is so small as to be insignificant.

The Meigs Creek seam is or has been mined in Seneca, Franklin and Bethel townships on the west side of the county. This territory may be regarded as an extension of the Noble county field. Another locality is near the village Mechanicsburg (Aitch P. O.) in Perry township.

As Andrews has stated the coals of this county are difficult to identify. This results from the absence of well marked horizons such as beds of fossiliferous limestone, from the thinness of the seams themselves, from the roughness of the topography and from the variations in the dip of the strata.

Seneca Township. In the northern part of this township the Meigs Creek coal is very thin or wholly wanting. On the farm of J. B. Williams in the southeast quarter of section 19, the coal has been stripped in the bed of a ravine. The following section was measured at that place:

	Ft.	In.
Limestone	1	6
Shales	2	3
Coal, poor quality	0	5
Coal	0	10
Coal, solid	0	8
Shales, unmeasured.		
Limestone, unmeasured.		

Usually the seam is about 2 feet thick but it is sometimes reported to measure 4 feet. Probably the coal is not of workable thickness in this township except in the two extreme southern sections.

Franklin Township. Along the west line of this township the Meigs Creek coal measures nearly 4 feet, sometimes more. For country banks, it is mined quite extensively, and is known as the Stafford coal. The mines, however, are across the line in Noble county.

The coal thins rapidly to the east, measuring only 18 inches on the

Hogue farm in section 9 where it has been mined by stripping. On the Baker farm in section 11, the following section of the coal was reported by the proprietor:

	Ft.	In.
Coal	0	6
Shales	0	6
Coal	1	6

The coal has been stripped on the Gibson farm in the northeast part of section 17, and is reported to be two feet thick.

The coal along the western border of this township appears to be valuable as a local fuel supply. Farther east it is much thinner, and is probably nowhere of workable thickness in the eastern part of the township.

Bethel Township. The Meigs Creek coal in this township is similar to that in Franklin. It is a well marked seam, and is mined in a small way on several farms.

On the Martin farm in section 3, the following measurement of the coal was furnished by the proprietor:

	Ft.	In.
Coal	2	6
Clay or shales	1	8
Coal	2	6

The soapstone varies from 15 to 24 inches in thickness. The bottom layer of coal is regarded the better, being harder and burning more freely.

At the Stoffel bank in section 11, the following measurement of the coal was made:

	Ft.	In.
Shales and sandstone, unmeasured.		
Coal	1	1
Clay or shales	1	8
Coal	3	0

As is usually the case the parting varies rapidly in thickness.

The coal is mined also on the neighboring farm of M. W. Dennis. These two banks supply the surrounding farmers with fuel, and also the oil fields in Sycamore valley and farther east in the county.

As in Franklin township the seam thins rapidly to the east and beyond the middle line of the township is rarely if ever of workable thickness.

The Mechanicsburg or Antioch Coal Field. This lies in the southeastern part of the county, and largely in Perry township.

The coal has long been mined in a small way for local use. A few years ago, the drilling for oil largely increased the demand, one mine employing 18 men. More recently the call has become much smaller and the present condition will probably be long maintained.

The following section was furnished as an average for the Bruce mine at Mechanicsburg:

	Ft.	In.
Shales, unmeasured.		
Coal	0	6
Shales	1	0
Coal	2	8
Hard soapstone, unmeasured.		

The top coal or Upper bench is reported to disappear entirely in places, and elsewhere to increase in thickness. Likewise the layer of shales varies, but rarely disappears. The lower coal is regarded superior in quality to the upper.

This coal is about 1170 feet above the Big Lime and about 1700 feet above the Berea grit. The character of the coal and its position with reference to the deeper formations just referred to proves it to be the Meigs Creek seam.

Just west of Mechanicsburg the coal disappears or is represented by a streak only, thus showing the unsteady nature of the seam. Northeast from this village the coal appears in the valley of the Little Muskingum River. The following is an average section of the seam in the Dryer bank in section 3 of Perry township, as furnished by the proprietor.

	Ft.	In.
Shales	10	0
Coal	0	10
Shales	0	1
Coal	0	5
Shales	0	½
Coal	0	4
Shales	1	0
Coal	0	5
Shales	0	2
Coal	0	8

Elsewhere along this valley the coal has occasionally been mined in a very small way. Rarely is the seam reported more than two feet in thickness, and sometimes less.

From what has been said it is plain that the Meigs Creek coal in this part of Monroe county is of little importance. At the best it cannot do more than meet a local demand from a small territory.

Switzerland and Salem Townships. These lie in the northeast corner of the county and the coal in question is everywhere due. From present data it cannot be asserted, however, that the coal is present in workable quantities.

Along the Ohio River in West Virginia, and opposite the territory in question, a number of tests have been made. Near Proctor the coal measured 2 feet 4 inches, and near Franklin Station, a few miles north, 3 feet 6 inches. These figures indicate an unsteady thickness of the seam

like that found in Ohio. They suggest also that the coal may be of value on the opposite side of the Ohio River, that is in Switzerland and Salem townships of Monroe county.

THE MEIGS CREEK COAL IN WASHINGTON COUNTY.

Aurelius Township. Nowhere in the county is the Meigs Creek coal better shown than in this township. Here as elsewhere in the county the seam is known as the Macksburg. This is a local name that has been applied to the seam by Minshall.[1] Andrews called it the Salem or Sandstone coal, because of its development near the village Salem, and because of its being often covered by a heavy bed of sandstone. He refers to it also as the Bear Creek, Coal Run or Cumberland seam.[2] Brown gave the seam in question the name Meigs Creek from its development along the stream of that name in Morgan county.[3]

Minshall has used the name Meigs Creek for a still higher seam. His succession being the Pittsburg coal, followed by the Macksburg and this by the Meigs Creek. The latter seam he places about 100 feet above the Macksburg. In other words he uses the name Macksburg for the same coal that Brown has named Meigs Creek.

The Meigs Creek coal of Brown is well shown along the valley of Duck Creek in the southern part of Noble county. Its position with reference to the Ames or Crinoidal limestone can be easily measured and thus the position of the coal determined. From the exposures of the seam along this valley, the coal can be followed to Macksburg, Washington county where it is about 290 feet above the Ames limestone and about 390 feet above the First Cow Run sand. There can be no doubt as to the Macksburg coal of Minshall being the Meigs Creek of Brown, and since the latter name has the claim of priority, it is used in this report.

The coal is exposed at many places in the township especially along the deep valley of Duck Creek and its tributaries.

Formerly the seam was mined for railroad shipment at Macksburg, but this has been discontinued many years. At present the fuel is mined on several farms for local use, among them the Dutton, Smithson, Wicksena, McManus, and Atkinson.

On the land of Charles Schimmel, section 28, one and one-half miles west of Elba, the coal was found as shown in section 52.

Pyrite lenses of considerable size are found in the coal but are not common. The coal is well spoken of by oil men who use it in boilers. No section showing the entire seam was found.

[1] Geol. Sur. of Ohio, Vol. VI, Chap. VI.
[2] Geol. Sur. of Ohio, Vol. II, Chap. LI.
[3] Geol. Sur. of Ohio, Vol. V, Chap. XIX.

SECTION 52

	Ft.	In.
5. Coal, lower part of upper bench,	0	9½
4. Shale, and soapstone,	1	3
3. Coal,	0	8
2. Shale,	0	⅜
1. Coal,	2	3¼

Chemical analysis and calorific value of Section 52:

Ultimate.		*Proximate.*	
Carbon	68.33	Moisture	3.40(a)
Hydrogen	5.31	Volatile Matter	37.95
Oxygen	10.85	Fixed carbon	49.07
Nitrogen	0.90	Ash	9.58
Sulphur	5.03		
Ash	9.58		
	100.00		100.00

Calorific value ..... 7,083 calories.

(a) Moisture in the air-dried sample about 2%.

Parts 1 and 3 only of the section were included in the sample which measured 4 by 2 inches. The face from which the sample was taken had been exposed for some weeks, and before sampling from 2 to 4 inches of the surface of the coal was removed.

The following is a section of the seam on the Dutton farm, near Elba:

	Ft.	In.
Shales, sandy, unmeasured.		
Coal, shaly, not mined	2	4
Shales and clay	2	6
Coal	4	6

On the land of A. F. Wooster along the valley of Duck Creek in the southern part of the township the following measurement of the coal was made:

	Ft.	In.
Coal	2	6
Shales	1	3
Coal	2	10

The quantity of this coal in Aurelius township is large and the quality fair. Probably it will not be mined on a large scale until the better coals of the state approach exhaustion. Then it will be of great value.

Salem Township. The Meigs Creek coal is shown almost everywhere in this township, along the valley of Duck Creek and its principal tributaries. In general the dip is to the southwest, but low undulations may vary it.

The seam has long been worked by farmers, and for an indefinite period will be their main reliance for fuel.

Along Bear Creek in the southwestern part of the township the seam is mined at two or three points for domestic purposes and also for work in the oil fields. On the land of George Bowen, one and one-half miles north of the township line, the coal is mined (1904) by Wagner Brothers. The seam here ranges in thickness from 4 feet to 4 feet 2 inches, is quite free from shale partings and is reported of good quality. Farther north along Bear Creek the coal thickens, measuring 5 feet. Southward the seam thins and near the mouth of this stream in Muskingum township the coal cannot be mined, or in fact be readily traced.

The thickness of this seam has been given in southern Aurelius township on Duck Creek just north of the township line. To the east and southeast from this place the coal thickens, becoming of importance along Duck Creek and the East Fork of this stream. A shale parting about one foot in thickness, near the middle of the seam, is a constant feature. The coal is fairly uniform in thickness and quality.

More than a mile northeast of Salem on the farm of Vincent Payne, the following measurement of the seam was made by Andrews:

	Ft.	In.
Coal, Upper bench	2	6
Clay parting	0	11
Coal, Lower bench	3	7

One mile southeast of Salem the following section was measured on the Twiggs farm on Paw-paw Creek:

	Ft.	In.
Coal	2	6
Shales	1	0
Coal	3	0

In the southern part of the township the seam thins, being about 4 feet on Pigeon Branch of Whipple Run, while farther south in Fearing township it becomes too thin to have any value except in the northeast corner, and is in fact difficult to trace.

Adams Township. The Meigs Creek coal is the only seam of importance in this township, and even this is of no value west of the Muskingum River. The coal usually lies a short distance only above drainage. It dips to the southwest.

Although the coal is found in the hills east of Lowell, it is not worked at present. Probably it is thinner there than farther northeast.

On the West Fork of Cats Creek the coal is mined in a small way at several places.

On the farm of William Henaker, two and one-half miles north of Lowell, two small mines are worked furnishing coal for the surrounding farmers and also for the oil fields. In one of these banks the coal varies in a short distance from 2 feet 3 inches to 3 feet in thickness. In the other bank the coal measures about 2 feet 6 inches. The operators claim that the seam here consists of only one of the benches which usually compose the Meigs Creek coal. The coal is hard and "rolly", and the roof of soft shale, preventing shooting and thus making the seam difficult to mine.

The seam is reported 3½ feet thick on the F. J. Bazil farm, one mile northwest of the Henaker farm. Andrews found the seam 4 feet 3 inches thick, slaty at the top, on the land of Nicholas Basil about three miles above the mouth of Cats Creek, while a mile farther south he found the following section on land of G. Brown:[1]

	Ft.	In.
Coal	1	6
Clay and shales	1	0
Coal	2	5

On Big Run in the western part of the township, the coal lies a few feet only above the stream bed. A number of banks have been opened along this stream but nearly all of these have been abandoned. On land of Henry Ross, a mile and one-half above the mouth of this creek, Andrews obtained the following section:[2]

	Ft.	In.
Coal	1	6
Clay	1	4
Coal	2	8

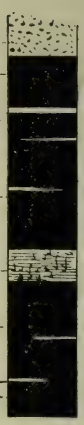
At the village Coal Run the seam dips below the level of the Muskingum River. The Felix mine, located about one-half mile below the village, is probably the second largest mine in this seam in Ohio, that at Flushing, Belmont county, ranking first. The main entry in the mine under consideration extends about half a mile into the hill, and a large quantity of coal has been removed. It has been worked at intervals since about 1890, furnishing coal to the farmers and occasionally small quantities are shipped by boat to Marietta. The maximum production was about the year 1900 when 600,000 bushels are reported to have been mined. When the mine was visited in July, 1904, the output was about 500 bushels per day. Section 53 represents the coal as found in this mine.

[1] Geol. Sur. of Ohio, Vol. II, pp. 476-477.

[2] Ibid, p. 476.

SECTION 53

	Ft.	In.
7. Soapstone, unmeasured,		
6. Coal,	0	6
5. Smut streak, sometimes has pyrites and shale,	0	3/8
4. Coal, including a pyrites streak and smut band,	1	4
3. Hard streak, coal with numerous pyrites and shale streaks,	0	3 3/4
2. Coal with 2 pyrites streaks,	0	11 3/4
1. Coal forming floor in entrys,	0	4



Chemical analysis and calorific value of Section 53:

Ultimate.		*Proximate.*	
Carbon	65.88	Moisture	2.95(a)
Hydrogen	5.05	Volatile Matter	37.47
Oxygen	9.71	Fixed carbon	46.69
Nitrogen	0.92	Ash	12.89
Sulphur	5.55		
Ash	12.89		
	100.00		100.00

Calorific value ..... 6,803 calories.

(a) Moisture in the air-dried sample about 2%.

Parts 1, 3 and 7 of the section were rejected in sampling. The sample measured 3 by 1½ inches.

Part 3 of the section was sampled separately and gave results as follows:

Ash	21.92
Sulphur	3.60

In the eastern part of the township the coal is of less importance. On Schlitzer's Fork of Cats Creek the seam is reported as consisting of two benches, each about 18 inches thick, separated by one foot of shale. The coal has been mined at several places along Middle Fork of Cats Creek in past years, but the banks have all been abandoned.

From what has been said it is seen that Adams township contains a large quantity of the Meigs Creek coal.

Waterford Township. The Meigs Creek coal occurs at about the river level at the village Coal Run along the eastern border of the township. Early settlers are reported to have stripped the coal from the river bed on the Shaw farm just above the village.

One and one-half miles east of Beverly the coal was formerly reached by a shaft on the J. W. Dana estate. According to Andrews the coal on this farm is as follows:[1]

	Ft.	In.
Blue clay shales	11	0
Coal	1	0
Clay	0	10
Coal	3	8

As has already been stated the Meigs Creek coal dips below the level of the river at Coal Run. It appears again in the valley of the river at and above Beverly, but is thinner, measuring only 9 inches near the river dam. Passing up the river the coal rises and becomes thicker, measuring from 2 to 3 feet near the mouth of Olive Green Creek and the post-office, Relief. This may be regarded as the southern margin of the most valuable part of the Meigs Creek coal fields.

On the extreme western border of the township the coal is lower owing to its westerly dip. The seam is much thinner also, measuring only from 7 to 11 inches on the Fisher farm, one and one-half miles south of Becketts Station.

A thin seam of coal is said to have been found in the bed of the lock at the Lake Chute dam. This may be the Meigs Creek seam though this is not certain. However, no coal was seen at or above the dam which could be referred to this seam. It has either dipped below the river or thinned out beyond recognition.

Decatur Township. The Meigs Creek coal is exposed only along Big Run in the extreme northwestern corner of the township. On the Duffie farm in section 6 where the coal has been mined the following section was measured:

	Ft.	In.
Coal	2	4
Shale	2	0
Coal	1	0

The coal dips below drainage at Morris' Station where it was formerly mined in a small way.

Except in this one section the coal is everywhere under cover in this township. No data are at hand showing the thickness or extent of the seam in this area. In fact this can be determined only by the drill.

Wesley Township. Two and one-half miles north of Bartlett, the Meigs Creek coal is exposed along Coal Run for a distance of one and one-half miles, being nowhere more than a few feet above the stream. Many years ago it was mined on the land of Joseph Wagoner on Coal Run where Andrews made the following measurement:[2]

[1] Ibid, pp. 470-1.

[2] Ibid, p. 463.

	Ft.	In.
Coal, shaly	0	8
Shale	0	2
Coal	2	0

This coal has been stripped on the land of Benj. Zumbro one and one-half miles below the Wagoner farm, and passes under cover at that place. When this territory was visited in 1905 the seam was being mined on the farm of Thomas Emmons, a short distance below the old Wagoner bank. In places the coal is overlain by a thick sandstone, the base of which sometimes curves down cutting out the coal in whole or in part.

On Wolf Creek into which Coal Run empties the horizon of the Meigs Creek coal is probably above drainage for a short distance. At the Morgan county line there is a small oil field in which the Cambridge limestone is reported to be about 320 feet below the valley of Wolf Creek. From this data the coal in question should be just above drainage. No trace of the coal, however, was seen either here or farther up this stream in Morgan county.

Liberty Township. The Meigs Creek coal is exposed in the valley of Paw-paw Creek and tributaries on the west side of the township and along Fifteen Mile Creek and tributaries in the southeastern part.

The coal is mined at several places along Campbell's Run in sections 27 and 28. In a cut at Germantown the following section of the seam was taken:

	Ft.	In.
Coal	2	6
Soapstone	1	6
Coal	3	0

It is customary in this locality to remove both divisions of the coal in mining. The lower one alone does not make a sufficiently high opening, and besides the soapstone above does not make a safe roof.

The following section of the coal was taken in the Ray bank, near the middle of section 8 in the southeastern corner of the township:

	Ft.	In.
Shale	10	0
Top coal	2	0
Soapstone	1	0
Lower coal	1	10

The soapstone layer between the two coals varies from 8 to 18 inches in thickness. The lower coal is reputed better than the upper one, but both are mined. This bank is the principal reliance of the farmers in this part of the township.

Liberty township contains a large quantity of the Meigs Creek coal, but as yet it has scarcely been touched. No shipping facilities exist, and hence mining simply meets the local needs.

Lawrence Township. The Meigs Creek coal varies considerably in this township. In the northwestern part it is of good thickness and quality, while in the eastern part it is thinner and nowhere mined. In the southeastern portion the seam is below drainage.

The following is a section of the coal in the Hamilton mine on Smoky Fork, northwest of Moss Run P. O.:

	Ft.	In.
Soapstone, unmeasured.		
Draw slate	0	4
Bone coal	0	4
Coal	4	4
Soapstone, unmeasured.		

The seam does not consist of the two benches so often found. Irregular masses of "sulphur rock" and other impurities however are occasionally found. Along Moss Run the nature of the roof varies, changing from shale to soapstone or sandstone. Occasionally a heavy ledge of the latter rock rests directly on the coal. The seam is unsteady in thickness, varying considerably in short distances. The section given above may be taken as an average.

Southwest of Moss Run P. O. the coal is much thinner, being, according to Andrews, only one foot 5 inches thick on the Baker farm in the southeastern part of section 27. Just west of the postoffice named above, Andrews found the seam 3 feet 4 inches in thickness, but it consists of four divisions, as shown below:

	Ft.	In.
Coal	0	4
Blue clay	1	8
Coal	0	4
Blue clay	1	0
Coal	1	4
Blue clay	2	1
Coal	1	4
Clay, not measured.		

Obviously the Meigs Creek coal in this territory is of a very uncertain nature. A section of the seam may be representative for the immediate area only. According to Andrews this seam dips beneath the Little Muskingum River, just below the mouth of Cow Run.[1] The exposure of the coal to which Andrews refers, in the bed of that stream, however, is no longer visible.

The coal has been mined on Cow Run about a mile above the postoffice, and also on the hillside just above the postoffice.

Newport Township. The only place in this township where the Meigs Creek coal is above drainage is along the Newell's Run uplift (Burning Springs anticlinal), about one mile west from the village Newport. This seam is now mined on the G. W. Smith farm, the coal

[1] Ibid, p. 496.

varying from 1½ to 3½ feet in thickness. Probably not more than one-third of the territory in that locality has the maximum thickness. The thinning of the seam appears to be due to the roof curving downward and cutting out the coal. The seam does not have the clay or shale parting near the middle which is so generally present. It has been worked in a small way in this neighborhood since the close of the civil war.

In the western part of the township, and especially on Long Run a higher seam is occasionally mined. On the Rightmire farm on this stream the following section was measured:

	Ft.	In.
Heavy sandstone, unmeasured.		
Shales	2	6
Coal	0	2
Shales and soapstone	1	11
Coal	5	0

This seam was formerly stripped in the bed of Long Run on the George Noland farm in section 22, but there it is only from 8 to 20 inches thick. The seam can be traced along this stream to its mouth, the Little Muskingum River. Rarely if ever is this coal found more than 20 feet above Long Run, a westward flowing stream, indicating that the coal dips to the west. This is to be expected since the territory is on the western slope of the Newells Run uplift. At the mouth of Long Run the Berea grit is about 1850 feet below the valley.

Ludlow Township. The Meigs Creek coal is above drainage on the western side of this township along the Little Muskingum river and its principal tributaries Sacketts and Wingetts Runs. The coal was formerly mined in a small way near Wingetts Run P. O., where the seam is reported to consist of two benches each two feet thick and separated by a layer of soapstone 18 inches in thickness.

On the McCurdy farm in the northwest quarter of section 34 the coal was found as follows:

	Ft.	In.
Coal	2	2
Soapstone	1	0
Coal	2	4

The seam has been worked in an irregular way in this locality for 25 years or more. Northeastward in this township the coal thins rapidly being only about 8 inches in thickness on the Payne farm in the southwest quarter of section 16. It has been stripped in the bed of a run on the McVay farm in the northwest quarter of section 10.

Obviously the seam is as uncertain in this township as in other parts of this county.

PART II.

Chemical Analyses and Calorific Tests of the Clarion, Lower Kittanning, Middle Kittanning and Upper Freeport Coals.

CHAPTER IV.

THE CLARION OR No. 4a COAL.[1]

This seam is important in four counties and is occasionally mined to a small extent in other parts of the state. The four counties are Vinton, Jackson, Lawrence and Scioto. The position of the seam is easily located by the Ferriferous limestone, the coal lying immediately below or separated from it by a thin bed of shales. The following sections illustrate this:[2]

Section on Rush Run, Milton township, Jackson county:

		Ft.	In.
Ferriferous limestone		3	0
Hard black shales		0	4
Clarion coal	Coal	1	6
	Shales	0	6
	Coal	2	0

Section at Olive Furnace, Washington township, Gallia county:

		Ft.	In.
Ferriferous limestone		8	0
Parting		0	3
Clarion coal	Coal	1	1
	Parting	0	6
	Coal	1	6
	Parting	0	1½
	Coal	0	7½

Fire clay, unmeasured.

These sections could be duplicated to almost any extent, and so represent very well the relation of the coal to the Ferriferous limestone.

As has already been stated the important deposit of this coal is restricted to four counties and in these its known areas form only a fractional part of the counties. In Jackson county Dr. Orton reports the seam in Lick, Franklin, Jefferson, Madison, Bloomfield and Milton townships; in Vinton county in Elk, Madison, Clinton, Vinton and Wilkesville townships; in Scioto county in Bloom and Vernon townships; in Gallia county in Greenfield township, and in Lawrence county in Washington and Decatur townships.

While the coal has long been mined for domestic purposes, it is comparatively recent that the seam has been worked in a large way. Its

[1] For method of sampling see Chapter IX.

[2] Geol. Sur. of Ohio, Vol. V, chapters XVII and XVIII.

close association geographically with the excellent Wellston coal, with which it has had to compete, has retarded its development. The coal has a good future. Its quality is shown by the following analyses.

CLARION COAL.

SAMPLE 54.

Hanging Rock Mine, section 34, Vinton township, Vinton county. Sample cut from two rooms, the face of the coal being fresh in each. Sampled by Professor Edward Orton, jr., in August, 1900.

Chemical analysis and calorific value of Sample 54:

Ultimate.		*Proximate.*	
Carbon	68.52	Moisture	5.02
Hydrogen	5.49	Volatile Comb	40.31
Oxygen	13.69	Fixed carbon	46.52
Nitrogen	1.28	Ash	8.15
Sulphur	2.87		
Ash	8.15		

Calorific value .....6,961 calories.

CLARION COAL.

SAMPLE 55.

Iron Valley Mine, section 35, Milton township, Jackson county. Sample cut from entry about 300 feet in. Mine had been idle two years but surface of coal appeared fresh. Sampled in 1900 by Professor Edward Orton, Jr.

Chemical analysis and calorific value of Sample 55:

Ultimate.		*Proximate.*	
Carbon	67.30	Moisture	5.61
Hydrogen	5.47	Volatile Comb.	38.92
Oxygen	14.16	Fixed carbon	47.38
Nitrogen	1.28	Ash	8.09
Sulphur	3.70		
Ash	8.09		

Calorific value .....6,863 calories.

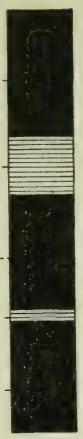
CLARION COAL.

SAMPLE AND SECTION 56.

Country Bank of Superior Coal Company, section 13, Milton township, Jackson county. Sample cut about 50 or 60 feet in the hill in comparatively new workings. Shale roof. Sampled by Professor Edward Orton, Jr., in August, 1900.

SECTION 56

	Ft.	In.
5. Coal, upper bench,	1	3
4. Shale parting,	0	7
3. Coal, middle bench,	1′–1½″ to 1	2
2. Shale parting,	0	1½
1. Coal, lower bench,	1	1½



Chemical analysis and calorific value of Sample 56:

Ultimate.		*Proximate.*	
Carbon	66.14	Moisture	4.98
Hydrogen	5.39	Volatile Comb.	39.71
Oxygen	13.31	Fixed carbon	45.51
Nitrogen	1.28	Ash	9.80
Sulphur	4.08		
Ash	9.80		

Calorific value ..... 6,801 calories.

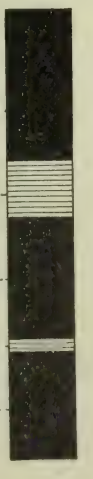
CLARION COAL.

SAMPLE AND SECTION 57.

Country Bank of Superior Coal Company, section 36 south, Milton township, Jackson county. Sample cut from 75 to 80 feet from entry. The mine had been worked recently and the surface of the coal appeared fresh. Sampled by Professor Edward Orton, Jr., in August, 1900.

SECTION 57

	Ft.	In.
5. Coal, upper bench,	1	6
4. Shale parting,	0	7
3. Coal, middle bench,	1	2½
2. Shale parting,	0	1½
1. Coal, lower bench,	1	1



Chemical analysis and calorific value of Sample 57:

Ultimate.		*Proximate.*	
Carbon	67.51	Moisture	4.71
Hydrogen	5.44	Volatile Comb.	40.51
Oxygen	13.45	Fixed carbon	46.17
Nitrogen	1.26	Ash	8.61
Sulphur	3.73		
Ash	8.61		

Calorific value ..... 6,911 calories.

CLARION COAL.

SAMPLE AND SECTION 58.

Mine of Vinton Coal Company, section 33, Vinton township, Vinton county. Sampled by Professor Edward Orton, Jr., in August, 1900.

SECTION 58

	Ft.	In.
7. Pyrites lenses and bone coal,	0	2
6. Coal, upper bench,	1	4
5. Shales and coal,	0	9
4. Coal, middle bench,	0	11
3. Shale parting,	0	1½
2. Coal, lower bench,	0	11
1. Clay, unmeasured,		

Chemical analysis and calorific value of Sample 58:

Ultimate.		*Proximate.*	
Carbon	64.91	Moisture	4.61
Hydrogen	5.36	Volatile Comb.	41.35
Oxygen	12.05	Fixed carbon	42.94
Nitrogen	1.30	Ash	11.10
Sulphur	5.28		
Ash	11.10		

Calorific value ..... 6,760 calories.

CLARION COAL.

SAMPLE AND SECTION 59.

Mine of Elmer Keck & Company, section 24, Wilkesville township, Vinton county. At point of sampling the limestone roof was replaced by sandstone. Sampled by Professor Edward Orton, Jr., in August, 1900.

SECTION 59

	Ft.	In.
5. Coal, upper bench,	1	3
4. Shale parting,	0	11
3. Coal, middle bench,	1	1½
2. Pyrites,	0	1½
1. Coal, lower bench,	1	2½

Chemical and calorific value of Sample 59:

Ultimate.		*Proximate.*	
Carbon	65.04	Moisture	4.72
Hydrogen	5.36	Volatile Comb.	39.88
Oxygen	12.95	Fixed carbon	44.19
Nitrogen	1.28	Ash	11.21
Sulphur	4.16		
Ash	11.21		

Calorific value ..... 6,744 calories.

CLARION COAL.

SAMPLE AND SECTION 60.

Pittinger Mine, Wellston, Jackson county. The coal has a shale roof. Sampled by Professor Edward Orton, Jr., in August, 1900.

SECTION 60

	Ft.	In.
6. Coal, upper bench,	0	11½
5. Shale parting,	0	9
4. Coal, middle bench,	1	4
3. Shale parting,	0	1½
2. Coal, lower bench,	1	2
1. Clay, unmeasured,		

Chemical analysis and calorific value of Sample 60:

Ultimate.		*Proximate.*	
Carbon	66.52	Moisture	5.33
Hydrogen	5.50	Volatile Comb.	41.01
Oxygen	14.58	Fixed carbon	45.26
Nitrogen	1.28	Ash	8.40
Sulphur	3.72		
Ash	8.40		

Calorific value ..... 6,825 calories.

CLARION COAL.

SAMPLE AND SECTION 61.

Lawler Mine, Minerton, Vinton county. Sampled by Professor Edward Orton, Jr., in August, 1900.

SECTION 61

	Ft.	In.
6. Coal, upper bench,	1	6½
5. Shale parting,	0	6½
4. Coal, middle bench,	1	2
3. Shale parting,	0	1½
2. Coal, lower bench, including a pyrites band near bottom,	1	1
1. Fire clay,		

Chemical analysis and calorific value of Sample 61:

Ultimate.		*Proximate.*	
Carbon	67.17	Moisture	4.52
Hydrogen	5.44	Volatile Comb.	40.10
Oxygen	13.03	Fixed carbon	46.53
Nitrogen	1.28	Ash	8.85
Sulphur	4.23		
Ash	8.85		

Calorific value ..... 6,904 calories.

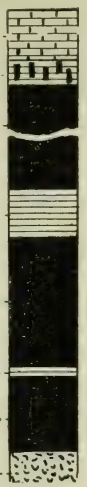
CLARION COAL.

SAMPLE AND SECTION 62.

Old Limestone Furnace Mine, section 32, Bloomfield township, Jackson county. Sample cut about 300 feet from entry. Limestone roof. Sampled by Professor Edward Orton, Jr., in August, 1900.

SECTION 62

	Ft.	In.
8. Limestone,	6	0
7. Bone coal,	0	3
6. Coal, upper bench,	7	10
5. Shale parting,	0	6
4. Coal, middle bench,	1	2½
3. Shale parting,	0	1½
2. Coal, lower bench,	0	9
1. Clay, unmeasured,		



Chemical analysis and calorific value of Sample 62:

Ultimate.		*Proximate.*	
Carbon	62.05	Moisture	5.31
Hydrogen	4.98	Volatile Comb.	37.33
Oxygen	12.12	Fixed carbon	43.82
Nitrogen	1.23	Ash	13.54
Sulphur	6.08		
Ash	13.54		

Calorific value ..... 6,394 calories.

CLARION COAL.

SAMPLE AND SECTION 63.

Hall's Mine, Kitchen station, Madison township, Jackson county. Sample cut well under the hill. Limestone roof. Sampled by Professor Edward Orton, Jr., in August, 1900.

Chemical analysis and calorific value of Sample 63:

Ultimate.		*Proximate.*	
Carbon	62.57	Moisture	4.90
Hydrogen	4.89	Volatile Comb.	35.75
Oxygen	11.47	Fixed carbon	45.65
Nitrogen	1.23	Ash	13.70
Sulphur	6.14		
Ash	13.70		

Calorific value ..... 6,460 calories.

CLARION COAL.

SAMPLE AND SECTION 64.

Mine of Morgan & Horton, Eifort station, Bloom township, Scioto county. Coal has ample cover. Sampled in August, 1901, by Professor Edward Orton, Jr.

Chemical analysis and calorific value of Sample 64:

Ultimate.		*Proximate.*	
Carbon	65.30	Moisture	6.80
Hydrogen	5.33	Volatile Comb.	37.92
Oxygen	15.35	Fixed carbon	45.94
Nitrogen	1.23	Ash	9.34
Sulphur	3.45		
Ash	9.34		

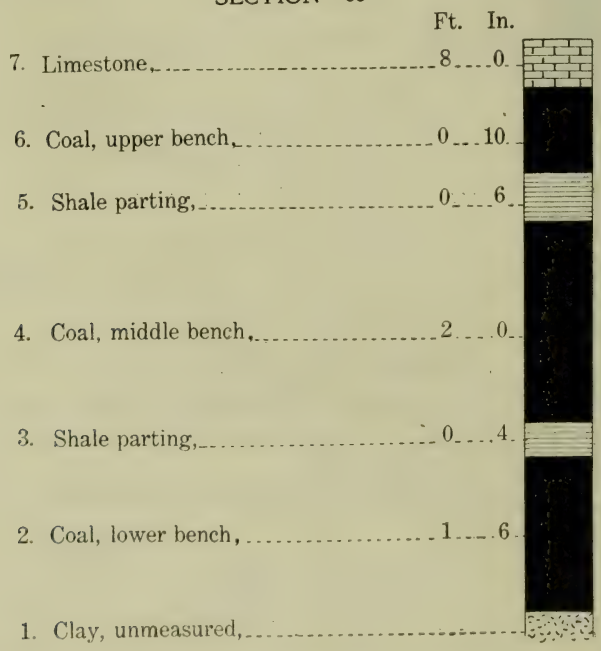
Calorific value ..... 6,577 calories.

CLARION COAL.

SAMPLE AND SECTION 65.

Mine of McGugin & Company, section 7, Decatur township, Lawrence county. The sample was cut from an old entry where the coal was weathered. Sampled in August, 1901, by Professor Edward Orton, Jr.

SECTION 65



Chemical analysis and calorific value of Sample 65:

Ultimate.		*Proximate.*	
Carbon	57.92	Moisture	6.34
Hydrogen	4.91	Volatile Comb.	35.30
Oxygen	13.40	Fixed carbon	40.95
Nitrogen	1.07	Ash	17.41
Sulphur	5.29		
Ash	17.41		

Calorific value ..... 5,967 calories.

CLARION COAL.

SAMPLE AND SECTION 66.

Mine of J. R. Edwards, section 23, Washington township, Lawrence county. Sample cut 75 feet from entrance to mine where the coal was fresh. Sampled by Professor Edward Orton, Jr., in August, 1901.

SECTION 66

	Ft.	In.
7. Limestone,		
6. Coal, upper bench,	1	0
5. Shale parting,	0	5
4. Coal, middle bench,	1	6
3. Shale parting,	0	2
2. Coal, lower bench,	0	6
1. Clay, unmeasured,		

Chemical analysis and calorific value of Sample 66:

Ultimate.		*Proximate.*	
Carbon	63.32	Moisture	6.00
Hydrogen	5.26	Volatile Comb.	39.16
Oxygen	13.24	Fixed carbon	42.98
Nitrogen	1.22	Ash	11.86
Sulphur	5.10		
Ash	11.86		

Calorific value ..... 6,519 calories.

CLARION COAL.

SAMPLE AND SECTION 67.

Mine of McGugin & Company, Olive Station, Decatur township, Lawrence county. Sample cut well under hill where coal was clean and bright. Sampled by Professor Edward Orton, Jr., in August, 1901.

Chemical analysis and calorific value of Sample 67:

Ultimate.		*Proximate.*	
Carbon	60.22	Moisture	5.86
Hydrogen	5.06	Volatile Comb.	37.25
Oxygen	12.90	Fixed carbon	41.61
Nitrogen	1.18	Ash	15.28
Sulphur	5.36		
Ash	15.28		

Calorific value ..... 6,185 calories.

SECTION 67

	Ft.	In.
6. Limestone,	7 to 8	0
5. Coal, upper bench,	0	11½
4. Shale parting,	0	5½
3. Coal, middle bench with 1 thin parting,	2	2½
2. Shale parting,	0	10½
1. Coal, lower bench,	1	6

CLARION COAL.

SAMPLE AND SECTION 68.

Mine of Isaac Hall, section 15, Decatur township, Lawrence county. Sample cut a half mile from entrance. Surface of coal had been exposed two months. Sampled by Professor Edward Orton, Jr., in August, 1901.

SECTION 68

	Ft.	In.
7. Limestone,		
6. Coal, upper bench,	1	0
5. Shale parting, 5 to 7 inches		
4. Coal, middle bench,	1	6
3. Shale parting, 2 to 3 inches		
Coal, lower bench, 6 to 7 inches		
1. Clay, unmeasured,		

Chemical analysis and calorific value of Sample 68:

Ultimate.		*Proximate.*	
Carbon	65.53	Moisture	6.11
Hydrogen	5.42	Volatile Comb.	38.43
Oxygen	14.28	Fixed carbon	45.52
Nitrogen	1.22	Ash	9.94
Sulphur	3.61		
Ash	9.94		

Calorific value ..... 6,643 calories.

CLARION COAL.

SAMPLE AND SECTION 69.

Mine of J. T. Dickson, section 27, Elk township, Vinton county. Coal had 50 feet cover. Sample cut from fresh surface by E. E. Somermeier in September, 1901.

SECTION 69

	Ft.	In.
5. Shale,		
4. Coal, upper bench,	0	8
3. Bone coal,	0	5
2. Shale parting,	0	5
1. Coal, lower bench,	2	10

Chemical analysis and calorific value of Sample 69:

Ultimate.		*Proximate.*	
Carbon	67.17	Moisture	4.95
Hydrogen	5.40	Volatile Comb.	39.17
Oxygen	13.28	Fixed carbon	46.56
Nitrogen	1.30	Ash	9.32
Sulphur	3.53		
Ash	9.32		

Calorific value ..... 6,914 calories.

CLARION COAL.

SAMPLE AND SECTION 70.

Mine of Trace, Rider & Plummer, section 29, Madison township, Vinton county. Sample cut well under the hill. Some doubt as to its

being the Clarion coal. Sampled by E. E. Somermeier in September. 1901.

SECTION 70

	Ft.	In.
5. Shale,		
4. Coal, upper bench,	1	7
3. Shale parting,	0	1
2. Coal, lower bench,	1	0
1. Clay, unmeasured,		

Chemical analysis and calorific value of Sample 70:

Ultimate.		*Proximate.*	
Carbon	67.92	Moisture	5.02
Hydrogen	5.48	Volatile Comb.	39.90
Oxygen	12.98	Fixed carbon	46.11
Nitrogen	1.33	Ash	8.97
Sulphur	3.32		
Ash	8.97		

Calorific value ..... 6,960 calories.

CHAPTER V.

THE LOWER KITTANNING OR NO. 5 COAL.[1]

This seam can be traced from Mahoning county southwest across the state to Lawrence. While it is mined in a number of places, it is of value in few.

The seam is important on the western side of Lawrence county, where it is known as the New Castle coal. The position of the seam is well shown by the following general section.[2]

Middle Kittanning or Sheridan seam, No. 6.
Interval 40 feet.
Lower Kittanning or Newcastle seam, No. 5.
Interval 20-30 feet.
Ferriferous limestone.
Interval 0-15 feet.
Clarion coal or Limestone seam, No. 4a.

The thickness and character of the coal in this field is adequately shown by the sections and analyses which follow. The coal is extensively used at Ironton, in fact is the main fuel reliance of that city.

The coal is found in fair thickness in the eastern part of Jackson county which lies north of Lawrence, but its development has been retarded by the presence of two more valuable seams, the Wellston and Clarion. It does not there promise to become more than a local source of fuel for years.

Northward from Jackson the seam thins until Perry county is reached. In the eastern part of this county especially in Clay and Pike townships it is important, and is known locally as the Lower New Lexington coal. Following is a generalized section of this part of the field.[3]

	Ft.
Lower Freeport sandstone or shale	30-40
Middle Kittanning coal, No. 6	5-13
Shales and Kidney ore	2-10
Sandy shale, mainly	10-20
Lower Kittanning coal, No. 5	1- 3
Kittanning clay and shales	10-20
Ferriferous limestone and Baird ore	1- 4

The two sections and analyses on a later page show very well the thickness, structure and composition of this coal.

[1] For method of sampling see Chapter IX.
[2] Geol. Sur. of Ohio, Vol, V, p. 1037.
[3] Vol. V, p. 919.

Continuing northeast Muskingum county is reached. There the coal is of some importance, especially in the vicinity of Zanesville and in Washington township. The area, however, is small. It is not found in workable thickness north of the Baltimore & Ohio Railroad nor is it found in the river hills south of the city. Sometimes the coal has three benches but occasionally the lower parting disappears. The seam is known locally as the "Four-foot" or Lower Zanesville.

Through the northern part of Muskingum county, through Coshocton and nearly the whole of Tuscarawas, the Lower Kittanning coal is thin and of little value. In Sandy township in the northeast corner of Tuscarawas county the coal is thicker, but the clay below the coal is often more valuable than the coal itself. The coal has long been mined in the vicinity of Mineral Point. It is an important local source of fuel and has been shipped for many years.

The coal is of some value in Pike and Sandy townships in the southeastern part of Stark county where it is mined in a small way for local use. The coal attains a thickness of about four feet. Sometimes it forms three benches and sometimes only two.

The coal is at its best in the northern part of Columbiana county, especially in the vicinity of Leetonia. Orton rated the field the most important of this seam in the state.[1] The area is not large but the coal is of good quality. It has been coked for local iron works. The seam usually has two benches "the lower of which is much the purer." Sometimes the upper bench has to be rejected. The following section shows the succession in this locality:

	Ft.	In.
Sandstone, Lower Freeport	20	0
Coal, Middle Kittanning	0	8
Sandstone and shales	15	0
Coal, Lower Kittanning	1	4
Shales and ore nodules	40	0
Draw slate	1	0
Coal, Clarion	3	0

From Columbiana county the coal can be traced northward into Mahoning. Probably Green township contains the best of the deposit. The area, however, is small and does not promise to become important except for a local demand. A section and analysis of the seam in this township may be found on a later page.

The seam is found also in the northern part of Jefferson county. It is there similar to the corresponding coal in Columbiana and Mahoning counties. The quantity, however, is small.

[1] Vol. V, p. 187.

LOWER KITTANNING COAL.

SAMPLE AND SECTION 71.

Copelin's Mine, section 2, Pike township, Perry county. The sample is an excellent one, and was cut from a section 12 by 5 inches. The No. 6 coal is found about 20 feet above the No. 5. Sampled by B. A. Eisenlohr in July, 1902.

SECTION 71

	Ft.	In.
7. Shale,	0	7
6. Coal, upper bench,	0	6
5. Horn coal,	0	1
4. Coal, middle bench,	1	0
3. Parting,	0	½
2. Coal, lower bench,	1	9
1. Fire clay,		

Chemical analysis and calorific value of Sample 71:

Ultimate.		*Proximate.*	
Carbon	64.78	Moisture	6.85
Hydrogen	5.26	Volatile Comb.	35.22
Oxygen	13.86	Fixed carbon	47.77
Nitrogen	1.22	Ash	10.16
Sulphur	4.72		
Ash	10.16		

Calorific value ..... 6,591 calories.

LOWER KITTANNING COAL.

SAMPLE AND SECTION 72.

McMonigal's Mine, section 14, Pike township, Perry county. Coal soft and dirty. Sample representative and cut from a section 18 by 4 inches by B. A. Eisenlohr in July, 1902.

Chemical analysis and calorific value of Sample 72:

Ultimate.		*Proximate.*	
Carbon	68.34	Moisture	6.74
Hydrogen	5.47	Volatile Comb.	37.05
Oxygen	15.25	Fixed carbon	49.09
Nitrogen	1.24	Ash	7.12
Sulphur	2.58		
Ash	7.12		

Calorific value ..... 6,885 calories.

SECTION 72

	Ft.	In.
6. Soapstone,		
5. Coal, soft and dirty,	1	6
4. Coal, upper bench,	0	6
3. Parting,	0	¾
2. Coal, lower bench,	2	4
1. Fire clay,		

LOWER KITTANNING COAL.

SAMPLE AND SECTION 73.

John Lutz Mine, Washington township, Muskingum county. Good sample cut from a section 14 by 4 inches by B. A. Eisenlohr in July, 1902.

SECTION 73

	Ft.	In.
8. Soapstone,		
7. Black shale,	0	4
6. Coal, upper bench,	1	8
5. Parting,	0	½
4. Coal, middle bench,	1	
3. Pyrites parting,	0	2
2. Coal, lower bench,	1	7
1. Fire clay,		

Chemical analysis and calorific value of Sample 73:

Ultimate.		*Proximate.*	
Carbon	68.07	Moisture	5.05
Hydrogen	5.37	Volatile Comb.	39.75
Oxygen	12.81	Fixed carbon	47.43
Nitrogen	1.18	Ash	7.77
Sulphur	4.80		
Ash	7.77		

Calorific value ..... 6,983 calories.

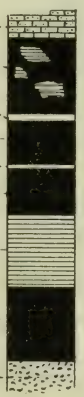
LOWER KITTANNING COAL.

SAMPLE AND SECTION 74.

Mine of John Peters, Coal Grove, Lawrence county. This is one of the southernmost mines in the state. The coal is used in burning brick and two or three mines are kept regularly at work. The sample was taken about one mile from the entrance where there was a vertical cover of 100 feet. While considerable water was in the mine, the sample was cut in a dry place and measured 5 by 3 inches. Sampled by D. D. Condit in November, 1907.

SECTION 74

	Ft.	In.
9. Sandstone,	15	0
8. Coal, shaly,	0	8¾
7. Shale,	0	1
6. Coal, upper bench,	0	5
5. Pyrites parting,	0	¼
4. Coal, middle bench,	0	5½
3. Gray shale,	0	8¾
2. Coal, lower bench,	0	9
1. Shale, unmeasured,		



Chemical analysis and calorific value of Sample 74:

Ultimate.		*Proximate.*	
Carbon	66.71	Moisture	7.57(a)
Hydrogen	5.59	Volatile Matter	38.51
Oxygen	14.44	Fixed carbon	45.13
Nitrogen	1.27	Ash	8.79
Sulphur	3.20		
Ash	8.79		
	100.00		100.00

Calorific value ..... 6,777 calories.

(a) Moisture in the air-dried sample from 2½ to 3 per cent.

LOWER KITTANNING COAL.

SAMPLE AND SECTION 75.

Mine No. 2 of the Halley Coal Company, Etna station, Lawrence county. Sample taken about 1,500 feet from entrance and where there was a vertical cover of 50 feet. The sample was cut from a fresh face and measured 5 by 3 inches. Taken by D. D. Condit in November, 1907.

SECTION 75

	Ft.	In.
6. Soapstone,	2	6
5. Bone coal	0	7½
4. Coal, upper bench and middle bench	2	2
3. Gray shale,	0	4
2. Coal, lower bench,	0	8
1. Shale, unmeasured,		

Chemical analysis and calorific value of Sample 75:

Ultimate.		*Proximate.*	
Carbon	65.54	Moisture	8.07(a)
Hydrogen	5.44	Volatile Matter	34.54
Oxygen	15.95	Fixed carbon	47.68
Nitrogen	1.23	Ash	9.71
Sulphur	2.13		
Ash	9.71		
	100.00		100.00

Calorific value ..... 6,626 calories.

(a) Moisture in the air-dried sample from 2½ to 3 per cent.

LOWER KITTANNING COAL.

SAMPLE AND SECTION 76.

Mine No. 11, Superior Coal Company, section 24, Milton township, Jackson county. Sample taken well under cover and from a fresh face. The sample was a section 5 by 4 inches and was cut by D. D. Condit in November, 1907.

SECTION 76

	Ft.	In.
8. Clay,	3	0
7. Bone coal,	1	1
6. Coal, upper bench,	2	3
5. Dark shale,	0	1
4. Coal, middle bench,	0	5
3. Clay,	0	2
2. Coal, lower bench,	0	3
1. Fire clay, unmeasured,		

Chemical analysis and calorific value of Sample 76:

Ultimate.		*Proximate.*	
Carbon	66.63	Moisture	8.39(a)
Hydrogen	5.47	Volatile Matter	35.18
Oxygen	16.46	Fixed carbon	49.01
Nitrogen	1.37	Ash	7.42
Sulphur	2.65		
Ash	7.42		
	100.00		100.00

Calorific value ..... 6,772 calories.

(a) Moisture in the air-dried sample from 2½ to 3 per cent.

LOWER KITTANNING COAL.

SAMPLE AND SECTION 77.

Huff Run Mine, No. 1, Mineral City, Tuscarawas county. Sample cut from a fresh face where the coal was well protected. Sample measured 4½ by 3 inches, and was cut by D. D. Condit, in December, 1907.

SECTION 77

		Ft.	In.
13.	Dark shale,		
12.	Coal,	0	8
11.	Bone coal,	0	⅜
10.	Coal,	0	1½
9.	Soot streak,	0	¼
8.	Coal,	1	1
7.	Pyrites,	0	¼
6.	Coal,	0	4¼
5.	Soot streak,	0	½
4.	Coal,	0	4½
3.	Bone coal,	0	½
2.	Coal,	0	9¼
1.	Fire clay,		

Chemical analysis and calorific value of Sample 77:

Ultimate.		*Proximate.*	
Carbon	69.75	Moisture	5.30(a)
Hydrogen	5.46	Volatile Matter	38.73
Oxygen	12.65	Fixed carbon	48.26
Nitrogen	1.18	Ash	7.71
Sulphur	3.25		
Ash	7.71		
	100.00		100.00

Calorific value ..... 7,168 calories.

(a) Moisture in the air-dried sample from 2½ to 3 per cent.

LOWER KITTANNING COAL.

SAMPLE AND SECTION 77a.

Mine of John D. Smith, Washingtonville, Green township, Mahoning county. Sample taken about 1,000 feet from entrance where the cover over the coal measured about 60 feet. The sample was a section 6 by 4 inches, and was cut by D. D. Condit, in December, 1907. The top 4 inches of the bone coal was rejected.

SECTION 77a

		Ft.	In.
5.	Shale with kidney ore,		
4.	Bone coal,	0	7
3.	Coal,	1	10
2.	Fire clay,		
1.	Limestone,		

Chemical analysis and calorific value of Sample 77a:

Ultimate.		*Proximate.*	
Carbon	73.84	Moisture	5.23(a)
Hydrogen	5.50	Volatile Matter	36.86
Oxygen	12.36	Fixed carbon	53.19
Nitrogen	1.41	Ash	4.72
Sulphur	2.17		
Ash	4.72		
	100.00		100.00

Calorific value ..... 7,592 calories.

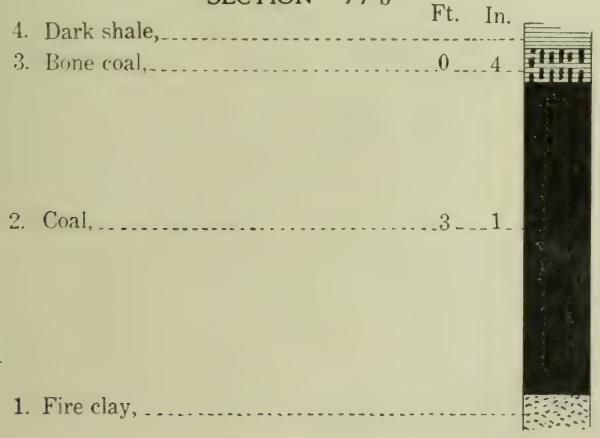
(a) Moisture in the air-dried sample from 2½ to 3 per cent.

LOWER KITTANNING COAL.

SAMPLE AND SECTION 77b.

Coal from mine of Great Western Sewer Pipe Works, Toronto, Jefferson county. The clay below the coal is removed and then the coal shot down. The coal is of secondary interest. The sample is fairly good and was cut by D. D. Condit, in December, 1907.

SECTION 77 b



Chemical analysis and calorific value of Sample 77b:

Ultimate.		*Proximate.*	
Carbon	74.20	Moisture	2.46(a)
Hydrogen	5.38	Volatile Matter	38.48
Oxygen	7.93	Fixed carbon	51.66
Nitrogen	1.27	Ash	7.40
Sulphur	3.82		
Ash	7.40		
	100.00		100.00

Calorific value ..... 7,591 calories.

(a) Moisture in the air-dried sample about one to one and one-half per cent.

CHAPTER VI.

THE MIDDLE KITTANNING OR NO. 6 COAL.[1]

This has always been considered the most valuable seam in Ohio. It extends entirely across the state from Columbiana to Lawrence counties, and is mined in a large or small way from the Pennsylvania line to the Ohio River. It is the most persistent seam in the state, though of course it varies in thickness from place to place.

It is mined in a small way at Sheridan, Lawrence county, in the extreme southern part of the state. A section of the seam at this place is given on a later page. There, however, the Lower Kittanning or New Castle coal is the more important.

Farther north in the county the coal is worked at a number of places and the quality is good, sometimes excellent.

The following section measured at Mt. Vernon Furnace shows very well the stratigraphy of the coal formations in this part of the state.[2]

	Ft.
Sandy shale with nodules of ore	12
Upper Freeport, No. 7 or Waterloo coal (Blossom)	
Sandy shales	11
Not seen	15
Shaly sandstone	12
Lower Freeport, No. 6 or Hatcher coal (Blossom)	
White clay	7
Shales	8
Sandstone	20
Slate	4
Middle Kittanning, No. 6, or Sheridan coal.	
Shales with kidneys of ore	16
Sandstone massive	29
Coal blossom.	
Shaly sandstone	7
Lower Kittanning, No. 5 or Newcastle coal.	
Not seen	8
White sandstone	6
Shales	4
Limestone ore.	
Ferriferous limestone	6
Clarion, No. 4a or Limestone coal.	
White sandstone	6
Coal blossom.	
Shales	16
Brookville, No. 4 coal.	
Sandstone	16
Not seen	6

[1] For method of sampling see Chapter IX.

[2] Vol. V, p. 1038.

From Lawrence county the seam extends across the northwest corner of Gallia where the coal is more valuable though not extensively mined. There the coal consists of three benches surmounted by a bed of clay, above which in turn is a thin layer of coal that Dr. Orton regarded as a continuation of the upper part of the great seam in the Hocking Valley.[1] The seam lies about 215 feet above the Cambridge limestone.

From Gallia the seam can be traced through the eastern part of Jackson county. There the coal is thinner and of less value. It cannot be mined for shipment as long as several thicker and more valuable seams are found in the same locality. The position of the seam is from 55 to 65 feet above the Ferriferous limestone.

The coal is found on the eastern side of Vinton county and has long been mined at Zaleski on the B. & O. S.-W. R. R. The seam consists of three benches, and the structure may be regarded normal for the state.

Continuing northeast Waterloo township, Athens county is reached and this constitutes the southwestern corner of the great Hocking Valley field. The most valuable part of this field includes the northern half of Athens, the eastern edge of Hocking and the southern third of Perry counties. Orton rated it the most important coal field in the state. Its only rival is the Pittsburg field of eastern Ohio whose output is increasing rapidly and will probably soon surpass that of the Hocking Valley field.

Concerning the structure of the seam in this field Dr. Orton has said:[2] "In structure the Hocking Valley coal always has the three benches of the normal Middle Kittanning seam, with some addition of its own. In other words the great vein consists of the normal three-bench seam of Middle Kittanning age covered and reinforced by a Hocking Valley supplementary seam, the latter consisting of one or two or more benches. The supplementary seam is separated from the original seam by a thin shale parting, which is often disregarded in mining, but which is for the most part distinctly recognizable when looked for."

"The supplementary seam of the Hocking Valley is, in the general view, counted with the upper bench of the normal seam, the whole being known as the top coal. It has a maximum thickness of 10 feet. All the thickness of the Hocking Valley seam in excess of 6 feet, and in many parts of the field all in excess of 4½ feet, is to be credited to the supplementary seam."

"There are numerous irregular partings in this top coal when it becomes thick, only one of which is widely extended and measurably regular. A four-inch black slate, known as the third slate, and charged with sigillaria impressions, is found 8 to 9 feet above the bottom of the Great Vein, everywhere throughout Monroe township, in the Sunday Creek Valley. As it now appears, it is the same horizon at which a constant layer of cannel or horn coal is found throughout the western por-

[1] Vol. V, p. 1047.
[2] Vol. V, p. 921.

tions of the Great Vein. The coal above the slate becomes a rider seam. It runs too high in ash in most of the field where it occurs to be fairly marketable. It reaches a maximum thickness of 4 feet, but most of it is left in the mines."

Concerning the character of the coal Dr. Orton said: "The character of the coal throughout the field is fairly uniform. Taken as a whole, it is an open-burning coal of pronounced character, but the lower bench, burned by itself, is somewhat cementing. It is distinctly laminated and holds a moderate proportion of mineral charcoal. It ignites easily, swells slightly in burning, and leaves a white or gray ash. It is well approved for steam generation, and also for rolling mill fuel. To household use it is admirably adapted, rivalling in this line of service the block coals of the Mahoning and Tuscarawas Valleys."

The numerous sections and analyses found on later pages amply show the thickness, structure and composition of the seam.

The following section measured in Monday Creek township on the extreme western edge of the Hocking Valley field shows the position of the Middle Kittanning with reference to the lower coals.[1]

	Ft.	In.
Middle Kittanning, No. 6, coal	3	0
Shales	24	0
Lower Kittanning, No. 5, coal	11	0
Ferriferous limestone and Baird ore	0	9
Interval	70	0
Upper Mercer limestone	1	3
Upper Mercer coal, No. 3a	3	0
Interval	45	0
Lower Mercer limestone.		

In Perry county northeast of the Hocking Valley field the seam under consideration thins but is nevertheless of value. It has long been worked and will increase in importance with the exhaustion of the richer territory already reviewed.

The seam is the main reliance of Muskingum county, both for domestic purposes and manufacturing. It extends across the county from the southwest to the northeast and is mined in the large or small way wherever present. It commonly ranges from 2½ to 3½ feet in thickness and is quite steady in thickness, structure and composition.

The seam is found in the southeastern part of Coshocton county and is the main reliance of that community for fuel. The seam commonly consists of two benches and over considerable of the territory ranges from 3 to 3½ feet in thickness. Its quality is good but in places the seam is too soft to bear transportation well.

In Tuscarawas county, lying east of Coshocton, the seam is found over a large area, existing in every township with the possible exception of Perry. It is at its best in the southeast corner where the coal occa-

[1] Vol. V, p. 907.

sionally reaches 5 feet in thickness. Usually the coal has the 3 benches which are so characteristic. In 1906 this county produced over 1,400,000 tons of coal, ranking seventh in the state. Much the larger part of this was from the seam under consideration.

Holmes county lies north of Coshocton and contains the Middle Kittanning seam over much of the southern part. The coal sometimes reaches 3½ feet in thickness and usually has two benches. Lack of transportation facilities has retarded the development of the seam but it has rendered marked service to the farmers.

The following section, taken in German township in the southeastern part of the county, shows very well the position of the seam with reference to the underlying strata:[1]

	Ft.
Gray shales	15
Black shales	6
Middle Kittanning coal (exposed)	2
Shale and clay	10
Sandstone	12
Shales with kidney ore	17
Lower Kittanning coal (exposed)	2
Clay	3
Shales with kidney ore	17
Sandstone	3
Clay blossom. Clarion?	
Shaly sandstone	22
Putnam Hill limestone	1
Brookville coal. Blossom.	
Sandstone with iron ore	15
Concealed	26
Upper Mercer coal	4

The Middle Kittanning coal is found in the western part of Carroll county, but it is there of comparatively small importance. According to Orton the Upper Freeport or No. 7 seam is the one valuable coal deposit of that county.[2]

The seam is found in the southeastern part of Stark county and has long been mined in a large or small way. The coal has a maximum thickness of nearly 4 feet and is of good quality. Sometimes only two benches are found and at other times three.

In this very rapid survey of the Middle Kittanning field Columbiana county has been reached. Dr. Orton thus speaks of the seam in this county: "The Middle Kittanning coal is less valuable, relatively and absolutely, in Columbiana county than in any other county of the state in which it occupies as wide an area. It is less than 1 foot in thickness wherever seen through the northern and central portions of the county, and is nowhere opened here. In the Ohio Valley it is known as the

[1] Vol. V, p. 840.
[2] Vol. V, p. 244.

Block Vein and as the Hammondville Strip Vein, and about East Liverpool as the Dry Run coal. Its quality here is so good that it is extensively worked in small mines, although its thickness ranges between 20 and 32 inches, rarely reaching the latter figure."[1]

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 78.

Bristol Coal Company, section 30, Pike township, Perry county. Mine was wet and muddy and some mud fell into the coal. Nevertheless the sample is believed to be fair. It was 10 inches wide and 5 inches deep, and was taken by B. A. Eisenlohr in July, 1902.

The No. 5 or Lower Kittanning seam was mined in the same locality.

SECTION 78

	Ft.	In.
6. Slate,		
5. Bone coal,	10 to 12	
4. Coal, upper bench,	1	3
3. Parting,	0	1½
2. Coal, lower bench,	1	7
1. Fire clay,		

Chemical analysis and calorific value of Sample 78:

Ultimate.		*Proximate.*	
Carbon	68.29	Moisture	7.00
Hydrogen	5.58	Volatile Comb.	37.12
Oxygen	15.59	Fixed carbon	48.93
Nitrogen	1.26	Ash	6.95
Sulphur	2.33		
Ash	6.95		

Calorific value ..... 6,880 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 79.

Upson Mine, section 21, Salt Lick township, Perry county. Soft coal above upper bench rejected. Sample, 6 inches wide and 4 inches deep, was taken by B. A. Eisenlohr in July, 1902.

[1] Vol. V, p. 186.

SECTION 79

	Ft.	In.
7. Soft coal,	6 to	18
6. Coal, upper bench,	4	3
5. Parting,	0	2½
4. Coal, middle bench,	1	6
3. Parting,	0	1
2. Coal, lower bench,	1	10
1. Fire clay,		

Chemical analysis and calorific value of Sample 79:

Ultimate.		*Proximate.*	
Carbon	68.30	Moisture	7.76
Hydrogen	5.46	Volatile Comb.	33.50
Oxygen	16.14	Fixed carbon	51.27
Nitrogen	1.18	Ash	7.47
Sulphur	1.45		
Ash	7.47		

Calorific value ..... 6,772 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 80.

Mine of Haydenville Coal Company, section 1, Green township, Hocking county. Thickness of seam is quite irregular. In places the upper bench is entirely wanting. Its greatest thickness is about 26 inches. The mine was dry and the sample very fair. Sampled by B. A. Eisenlohr in July, 1902.

The No. 5 or Lower Kittanning seam was noted about 33 feet below and approximately 28 inches thick.

SECTION 80

	Ft.	In.
8. Sandstone,		
7. Draw slate,	0	4
6. Coal, upper bench,	1	3
5. Parting,	0	3
4. Coal, middle bench,	2	2½
3. Parting,	0	4
2. Coal, lower bench,	1	1
1. Fire clay,		

Chemical analysis and calorific value of Sample 80:

Ultimate.		*Proximate.*	
Carbon	68.40	Moisture	6.55
Hydrogen	5.45	Volatile Comb.	37.30
Oxygen	15.43	Fixed carbon	49.18
Nitrogen	1.18	Ash	6.97
Sulphur	2.57		
Ash	6.97		

Calorific value .....6,901 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 81.

Mine of J. W. Washburn, section 22, Starr township, Hocking county. The roof is undulating and hence the thickness of the coal varies. The lower bench as well as the upper thins out in places. Sample 14 inches wide by 4½ inches in depth. A little dirt fell into the sample, which was taken by B. A. Eisenlohr in July, 1902.

SECTION 81

	Ft.	In.
6. Sandstone,		
5. Draw slate,	0	6½
4. Coal, upper bench,	2	6
3. Parting,	0	1
2. Coal, lower bench,	0	5
1. Fire clay,		

Chemical analysis and calorific value of Sample 81:

Ultimate.		*Proximate.*	
Carbon	67.33	Moisture	6.52
Hydrogen	5.49	Volatile Comb.	38.30
Oxygen	14.43	Fixed carbon	47.15
Nitrogen	1.20	Ash	8.03
Sulphur	3.52		
Ash	8.03		

Calorific value ..... 6,850 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 82.

Bank of George Cherry, section 3, Swan township, Vinton county. Upper bench much harder than lower one. Sample cut about 60 feet from outcrop and is very good. It was taken by B. A. Eisenlohr in July, 1902.

Chemical analysis and calorific value of Sample 82:

Ultimate.		*Proximate.*	
Carbon	66.26	Moisture	4.90
Hydrogen	5.40	Volatile Comb.	39.16
Oxygen	12.71	Fixed carbon	45.79
Nitrogen	1.23	Ash	10.15
Sulphur	4.25		
Ash	10.15		

Calorific value ..... 6,845 calories.

SECTION 82

	Ft.	In.
5. Shale,	2	2½
4. Coal, upper bench,	1	8
3. Parting,	0	2
2. Coal, lower bench	0	11
1. Bone coal,	0	8

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 82a.

Mine of G. L. Chatfield, Sheridan, Lawrence county, the location being at almost the southernmost point in the state. The mine is small and probably never yields more than 200 bushels per day. The sample was taken about 300 feet from the entrance where the vertical cover was about 250 feet. The face from which the coal was cut had been exposed only three days. Sample consists of a section about 5 by 3 inches and was cut by D. D. Condit in November, 1907.

SECTION 82 a

	Ft.	In.
5. Shale, unmeasured,		
4. Coal with shale,	0	6
3. Shale persistent,	0	½
2. Coal,	2	6
1. Shale, unmeasured,		

Chemical analysis and calorific value of Sample 82a:

Ultimate.		*Proximate.*	
Carbon	64.95	Moisture	6.64(a)
Hydrogen	5.16	Volatile Matter	34.28
Oxygen	14.42	Fixed carbon	48.16
Nitrogen	1.23	Ash	10.92
Sulphur	3.32		
Ash	10.92		
	100.00		100.00

Calorific value .....6,626 calories.

(a) Moisture in the air-dried sample from 2½ to 3 per cent.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 82b.

Mine of Black Diamond Coal Company, section 9, Greenfield township, Lawrence county. The sample was taken from a fresh face, well under cover and measured 6 by 4 inches. The upper bench is less pure and varies much in thickness. The thin coal at the bottom is not mined and was rejected in sample. The latter was taken by D. D. Condit in November, 1906.

SECTION 82 b

	Ft.	In.
7. Gray shale,		
6. Coal, upper bench,	1	0
5. Clay,	0	5½
4. Coal, middle bench,	1	10½
3. Shale,	0	1
2. Coal, lower bench,	0	2
1. Clay, unmeasured,		

Chemical analysis and calorific value of Sample 82b:

Ultimate.		*Proximate.*	
Carbon	65.71	Moisture	8.08(a)
Hydrogen	5.48	Volatile Matter	37.53
Oxygen	15.47	Fixed carbon	45.87
Nitrogen	1.18	Ash	8.52
Sulphur	3.64		
Ash	8.52		
	100.00		100.00

Calorific value .....6,717 calories.

(a) Moisture in the air-dried sample from 2½ to 3 per cent.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 83.

Mine of Luhrig Coal Company, section 4, Athens township, Athens county. The sample was 3½ inches wide and 5 inches deep, and was taken by B. A. Eisenlohr in July, 1902. Sample regarded first class.

The Upper Freeport or No. 7 coal lies about 75 feet higher and is 4 inches thick.

SECTION 83

	Ft.	In.
9. Slate,		
8. Coal, upper bench,	2	5
7. Parting,	0	4
6. Coal, upper bench,	1	9
5. Parting,	0	2½
4. Coal, middle bench,	1	9
3. Parting,	0	1
2. Coal, lower bench,	0	9
1. Fire clay,		

Chemical analysis and calorific value of Sample 83:

Ultimate.		*Proximate.*	
Carbon	69.22	Moisture	6.17
Hydrogen	5.43	Volatile Comb.	36.40
Oxygen	15.33	Fixed carbon	49.61
Nitrogen	1.30	Ash	7.82
Sulphur	0.90		
Ash	7.82		

Calorific value ..... 6,868 calories.

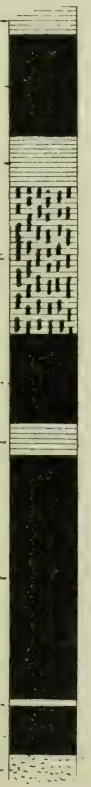
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 84.

Mine of Carbondale Coal Company, section 36, Waterloo township, Athens county. The sample is very fair. It measured 16 inches in width and 4½ inches in depth, and was taken by B. A. Eisenlohr in August, 1902.

SECTION 84

		Ft.	In.
10.	Shale		
9.	Rooster coal, rejected,	1	0
8.	Hard shale,	0	6
7.	Bone coal,	1	6
6.	Coal, upper bench,	0	10
5.	Parting,	0	4
4.	Coal, middle bench,	2	4
3.	Parting,	0	1
2.	Coal, lower bench,	0	6
1.	Fire clay,		



Chemical analysis and calorific value of Sample 84:

Ultimate.		*Proximate.*	
Carbon	69.21	Moisture	6.70
Hydrogen	5.49	Volatile Comb.	35.36
Oxygen	15.09	Fixed carbon	51.19
Nitrogen	1.18	Ash	6.75
Sulphur	2.28		
Ash	6.75		

Calorific value ..... 6,921 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 85.

Mine of J. P. Hardy, section 27 or 28, Waterloo township, Athens county. Sample very good, taken by B. A. Eisenlohr in July, 1902.

SECTION 85

	Ft.	In.
5. Shale,		
4. Coal, upper bench,	2	0
3. Shale,	0	1
2. Coal, lower bench,	0	8
1. Fire clay,		

Chemical analysis and calorific value of Sample 85:

Ultimate.		*Proximate.*	
Carbon	67.40	Moisture	6.80
Hydrogen	5.49	Volatile Comb.	36.90
Oxygen	15.55	Fixed carbon	48.25
Nitrogen	1.37	Ash	8.05
Sulphur	2.14		
Ash	8.05		

Calorific value ..... 6,794 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 86.

Mine of Continental Coal Company, section 4 or 5, Ward township, Hocking county. The sample measured 6½ by 5 inches and is excellent. Taken by B. A. Eisenlohr in July, 1902.

Chemical analysis and calorific value of Sample 86:

Ultimate.		*Proximate.*	
Carbon	70.05	Moisture	7.55
Hydrogen	5.52	Volatile Comb.	34.03
Oxygen	16.39	Fixed carbon	52.57
Nitrogen	1.42	Ash	5.85
Sulphur	0.77		
Ash	5.85		

Calorific value ..... 6,950 calories.

SECTION 86

	Ft.	In.
9. Slate,		
8. Coal, upper bench,	2	0
7. Parting,	0	3
6. Coal, middle bench,	3	0
5. Parting,	0	5
4. Coal, middle bench,	1	5
3. Parting,	0	1
2. Coal, lower bench,	2	1
1. Fire clay,		

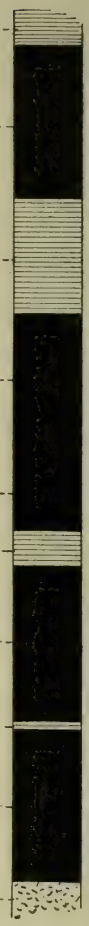
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 87.

Mine of New Pittsburg Coal Company, section 7, Ward township, Hocking county. Sample, 12 by 5 inches in cross section, taken by B. A. Eisenlohr in July, 1902.

SECTION 87

	Ft.	In.
10. Shale,		
9. Splint coal,	1	6
8. Black shale,	1	2
7. Coal, upper bench,	1	3
6. Soft coal, rejected,	0	10
5. Shale,	0	4
4. Coal, middle bench,	1	6
3. Shale,	0	1
2. Coal, lower bench,	1	6
1. Fire clay,		



Chemical analysis and calorific value of Sample 87:

Ultimate.		*Proximate.*	
Carbon	71.04	Moisture	7.45
Hydrogen	5.53	Volatile Comb.	35.01
Oxygen	16.53	Fixed carbon	52.73
Nitrogen	1.43	Ash	4.81
Sulphur	0.66		
Ash	4.81		

Calorific value ..... 7,057 calories.

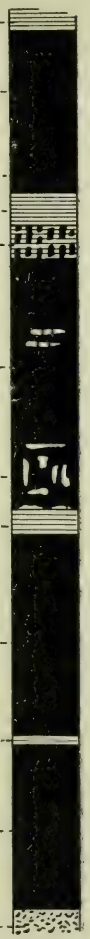
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 88.

Green & Hite Mine, Ward township, Hocking county. The sample was 8 by 5 inches in cross section and was a very good one. Taken by B. A. Eisenlohr in July, 1902.

SECTION 88

	Ft.	In.
12. Slate,		
11. Coal,	1	3
10. Bastard cannel,	0	4
9. Slate,	0	4
8. Bone coal,	0	4
7. Coal, upper bench,	1	10
6. Soft coal,	0	8
5. Parting,	0	3
4. Coal, middle bench,	2	0
3. Parting,	0	1
2. Coal, lower bench,	1	8
1. Fire clay,		



Chemical analysis and calorific value of Sample 88:

Ultimate.		*Proximate.*	
Carbon	70.58	Moisture	7.40
Hydrogen	5.55	Volatile Comb.	34.17
Oxygen	16.49	Fixed carbon	53.43
Nitrogen	1.32	Ash	5.00
Sulphur	1.06		
Ash	5.00		

Calorific value ..... 7,027 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 89.

Mine of Continental Coal Company, section 27, Dover township, Athens county. Sample 14 inches wide and 5 inches deep. Very good sample, taken by B. A. Eisenlohr in July, 1902.

This coal is reached by a shaft 117 feet deep. Lying about 80 feet above this coal, the No. 7 seam was found 3½ feet thick.

SECTION 89

	Ft.	In.
11. Soapstone,		
10. Coal,	1	6
9. Shale,	0	4
8. Bone coal,	0	8
7. Coal, upper bench,	1	6
6. Soft coal,	0	5
5. Shale,	0	3
4. Coal, middle bench,	1	6
3. Shale,	0	1
2. Coal, lower bench,	1	8
1. Fire clay,		

Chemical analysis and calorific value of Sample 89:

Ultimate.		*Proximate.*	
Carbon	69.32	Moisture	7.14
Hydrogen	5.56	Volatile Comb.	34.22
Oxygen	15.45	Fixed carbon	51.92
Nitrogen	1.30	Ash	6.72
Sulphur	1.65		
Ash	6.72		

Calorific value ..... 6,863 calories.

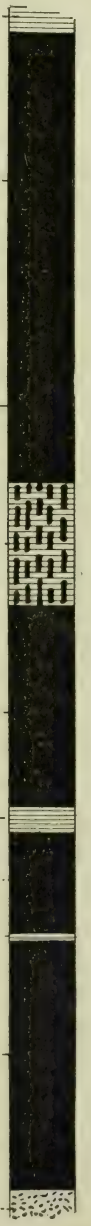
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 90.

Continental Coal Company, Mine No. 4, section 8, Trimble township. Athens county. Coal reached by a shaft 135 feet deep. Sample 8 by 7 inches, taken by B. A. Eisenlohr in July, 1902.

SECTION 90

	Ft.	In.
10. Slate,		
9. Rooster coal,	3	0
8. Cannel coal,	1	6
7. Bone coal,	1	3
6. Coal, upper bench,	2	0
5. Parting,	0	3
4. Coal, middle bench,	1	0
3. Parting,	0	1
2. Coal, lower bench,	2	6
1. Fire clay,		



Chemical analysis and calorific value of Sample 90:

Ultimate.		*Proximate.*	
Carbon	69.46	Moisture	7.28
Hydrogen	5.45	Volatile Comb.	32.38
Oxygen	16.16	Fixed carbon	53.61
Nitrogen	1.34	Ash	6.73
Sulphur	0.86		
Ash	6.73		

Calorific value .....6894 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 89a.

Mine of Canaanville Coal Company, Canaan township, Athens county. This is a shaft mine, 412 feet in depth. The sample was cut near the air shaft and measured 5 by 3 inches. The lower bench of the coal was wet. Sampled by D. D. Condit in November, 1907.

SECTION 89a

	Ft.	In.
9. Shale, unmeasured,		
8. Coal,	0	10
7. Shale,	0	3
6. Coal, upper bench,	1	7
5. Shale,	0	2 ¾
4. Coal, middle bench,	0	6 ½
3. Bone coal,	0	1½
2. Coal, lower bench,	2	4
1. Clay, unmeasured,		

Chemical analysis and calorific value of Sample 89a:

Ultimate.		*Proximate.*	
Carbon	69.25	Moisture	6.36(a)
Hydrogen	5.40	Volatile	34.19
Oxygen	14.92	Fixed carbon	50.96
Nitrogen	1.43	Ash	8.49
Sulphur	0.51		
Ash	8.49		
	100.00		100.00

Calorific value .....6,919 calories.

(a) Moisture in the air-dried sampde from 2½ to 3 per cent.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 91.

S. C. C. Company, Mine No. 8, section 9, Monroe township, Perry county. Excellent sample 8 inches wide and 4 deep, made by B. A. Eisenlohr in July, 1902.

Chemical analysis and calorific value of Sample 91:

Ultimate.		*Proximate.*	
Carbon	70.30	Moisture	6.79
Hydrogen	5.49	Volatile Comb.	35.45
Oxygen	16.00	Fixed carbon	51.85
Nitrogen	1.30	Ash	5.91
Sulphur	1.00		
Ash	5.91		

Calorific value .....6,983 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 92.

E. E. Tharp's Mine, section 14, Pike township, Perry county. Sample 10 by 5 inches, and was taken by B. A. Eisenlohr in July, 1902. Sample very good.

Chemical analysis and calorific value of Sample 92:

Ultimate.		*Proximate.*	
Carbon	66.05	Moisture	5.25
Hydrogen	5.38	Volatile Comb.	38.85
Oxygen	14.10	Fixed carbon	46.04
Nitrogen	1.18	Ash	9.86
Sulphur	3.43		
Ash	9.86		

Calorific value .....6,773 calories.

SECTION 91

	Ft.	In.
6. Shale,		
5. Top coal,	3	0
4. Coal, upper bench,	3	0
3. Bone coal,	2	5
2. Coal, lower bench,	2	4
1. Fire clay,		

SECTION 92

	Ft.	In.
6. Sandstone,		
5. Coal, upper bench,	2	0
4. Pyrites,	0	4
3. Coal, lower bench,	2	8
2. Bottom coal,	0	2
1. Fire clay,		

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 93.

National Fuel Company, Mine 34, section 3, Bearfield township, Perry county. Sample about 20 inches wide and 4 deep, taken by B. A. Eisenlohr in July, 1902.

SECTION 93

	Ft.	In.
7. Shale,		
6. Coal, upper bench,	0	8
5. Pyrites,		
4. Coal, middle bench,	0	6
3. Parting,	0	1
2. Coal, lower bench,	2	6
1. Fire clay,		

Chemical analysis and calorific value of Sample 93:

Ultimate.		*Proximate.*	
Carbon	65.43	Moisture	5.90
Hydrogen	5.26	Volatile Comb.	36.58
Oxygen	13.03	Fixed carbon	47.42
Nitrogen	1.22	Ash	10.10
Sulphur	4.96		
Ash	10.10		

Calorific value ..... 6,686 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 94.

Keystone Mine, No. 1, section 20 and 29, Harrison township, Perry county. Sample very good, cut from section 2 feet wide and 4 inches deep by B. A. Eisenlohr in July, 1902.

SECTION 94

	Ft.	In.
9. Soapstone,		
8. Bone coal,	0	8
7. Draw slate,	0	2
6. Coal, upper bench,	1	4
5. Parting,	0	1
4. Coal, middle bench,	0	7
3. Pyrites,	0	1
2. Coal, lower bench,	1	6
1. Fire clay,		

Chemical analysis and calorific value of Sample 94:

Ultimate.		*Proximate.*	
Carbon	69.77	Moisture	7.21
Hydrogen	5.60	Volatile Comb.	37.60
Oxygen	15.77	Fixed carbon	49.93
Nitrogen	1.26	Ash	5.26
Sulphur	2.34		
Ash	5.26		

Calorific value ..... 7,008 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 95.

Yost's Mine, section 18, Clayton township, Perry county. Sample about 21 by 7 inches, cut by B. A. Eisenlohr in July, 1902.

SECTION 95

	Ft.	In.
9. Soapstone,	6	0
8. Black shale,	1	1
7. Bone coal,	0	6
6. Coal, upper bench,	0	8
5. Parting,	0	¼
4. Coal, middle bench,	0	6
3. Parting,	0	3
2. Coal, lower bench,	1	6
1. Fire clay,		

Chemical analysis and calorific value of Sample 95:

Ultimate.		*Proximate.*	
Carbon	68.45	Moisture	6.72
Hydrogen	5.61	Volatile Comb.	38.30
Oxygen	15.58	Fixed carbon	48.34
Nitrogen	1.29	Ash	6.64
Sulphur	2.43		
Ash	6.64		

Calorific value ..... 6,903 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 96.

S. T. Jones' Mine, section 14, Newton township, Muskingum county. Sample 18 by 5 inches, cut by B. A. Eisenlohr in July, 1902. Seventy feet below this, another seam was observed with a blue fossiliferous limestone overlying it.

Chemical analysis and calorific value of Sample 96:

Ultimate.		*Proximate.*	
Carbon	65.88	Moisture	5.02
Hydrogen	5.29	Volatile Comb.	38.16
Oxygen	12.18	Fixed carbon	47.26
Nitrogen	1.12	Ash	9.56
Sulphur	5.97		
Ash	9.56		

Calorific value ..... 6,758 calories.

SECTION 96

	Ft.	In.
5. Bone coal,	0	8
4. Coal, upper bench,	1	10
3. Parting,	0	1
2. Coal, lower bench,	1	7
1. Fire clay,		

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 97.

Mine of the New Crescent Mining Company, section 5, Harrison township, Perry county. Sample excellent, cut from a section 18 by 5 inches by B. A. Eisenlohr in July, 1902.

SECTION 97

	Ft.	In.
7. Soapstone,		
6. Bone coal,	1	0
5. Shale,	0	2
4. Coal, upper bench,	1	7
3. Parting,		
2. Coal, lower bench,	2	3
1. Fire clay,		

Chemcial analysis and calorific value of Sample 97:

Ultimate.		*Proximate.*	
Carbon	67.77	Moisture	5.70
Hydrogen	5.37	Volatile Comb.	38.83
Oxygen	13.85	Fixed carbon	47.02
Nitrogen	1.18	Ash	8.45
Sulphur	3.38		
Ash	8.45		

Calorific value ..... 6,851 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 98.

Mine of Hamilton & Wallace Coal Company, section 13, Harrison township, Perry county. Sample cut near the face of a new opening about 150 feet from mouth of the mine. Sample about 15 by 6 inches, cut by B. A. Eisenlohr in July, 1902.

SECTION 98

	Ft.	In.
9. Soapstone,		
8. Bone coal,	1	1
7. Shale,	0	2
6. Coal, upper bench,	0	6
5. Parting,	0	1
4. Coal, middle bench,	0	8
3. Parting,	0	1½
2. Coal, lower bench,	1	10
1. Fire clay,		

Chemical analysis and calorific value of Sample 98:

Ultimate.		*Proximate.*	
Carbon	68.06	Moisture	6.40
Hydrogen	5.49	Volatile Comb.	38.00
Oxygen	14.89	Fixed carbon	48.02
Nitrogen	1.26	Ash	7.58
Sulphur	2.72		
Ash	7.58		

Calorific value ..... 6,867 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 99.

Mine of Frank Lacey, Washington township, Muskingum county. Excellent sample cut from a section about 24 by 6 inches, by B. A. Eisenlohr in July, 1902.

SECTION 99

	Ft.	In.
6. Soapstone,		
5. Shale,	0	2
4. Coal, upper bench,	1	8
3. Pyrites,	0	2
2. Coal, lower bench,	0	7
1. Fire clay,		

Chemical analysis and calorific value of Sample 99:

Ultimate.		*Proximate.*	
Carbon	67.16	Moisture	5.44
Hydrogen	5.34	Volatile Comb.	39.15
Oxygen	13.27	Fixed carbon	46.13
Nitrogen	1.18	Ash	9.28
Sulphur	3.77		
Ash	9.28		

Calorific value ..... 6,822 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 100.

Mine of Wesley Wells, section 30 or 31, Harrison township, Muskingum county. Excellent sample cut from section about 22 by 6 inches, by B. A. Eisenlohr in August, 1902.

SECTION 100

	Ft.	In.
6. Sandstone,		
5. Shale,	15	0
4. Coal, upper bench,	1	1
3. Parting,	0	2
2. Coal, lower bench,	1	1
1. Fire clay,		

Chemical analysis and calorific value of Sample 100:

Ultimate.		*Proximate.*	
Carbon	67.71	Moisture	4.67
Hydrogen	5.38	Volatile Comb.	40.32
Oxygen	11.82	Fixed carbon	45.18
Nitrogen	1.16	Ash	9.83
Sulphur	4.10		
Ash	9.83		

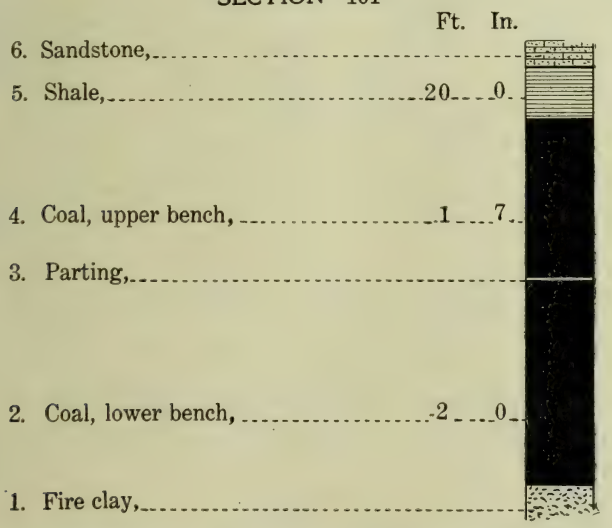
Calorific value ..... 6,873 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 101.

Mine of Walnut Hill Coal Company, section 13, Brush Creek township, Muskingum county. Excellent sample, about 13 by 7 inches, cut by B. A. Eisenlohr in August, 1902.

SECTION 101



Chemical analysis and calorific value of Sample 101:

Ultimate.		*Proximate.*	
Carbon	65.74	Moisture	5.08
Hydrogen	5.32	Volatile Comb.	39.75
Oxygen	12.49	Fixed carbon	45.40
Nitrogen	1.14	Ash	9.77
Sulphur	5.54		
Ash	9.77		

Calorific value ..... 6,802 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 102.

Mine of E. R. Birkhimer, Madison township, Muskingum county. Excellent sample, about 24 by 5 inches, and cut by B. A. Eisenlohr in August, 1902.

SECTION 102

	Ft.	In.
5. Soapstone,	3	0
4. Coal, upper bench,	2	1
3. Parting,	0	1½
2. Coal, lower bench,	0	7
1. Fire clay,		

Chemical analysis and calorific value of Sample 102:

Ultimate.		*Proximate.*	
Carbon	66.69	Moisture	4.75
Hydrogen	5.35	Volatile Comb.	39.88
Oxygen	12.05	Fixed carbon	46.09
Nitrogen	1.28	Ash	9.28
Sulphur	5.35		
Ash	9.28		

Calorific value ..... 6,854 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 103.

Mine of E. U. Farrell, Madison township, Muskingum county. Excellent sample, about 20 by 5 inches, and cut by B. A. Eisenlohr in August, 1902.

SECTION 103

	Ft.	In.
6. Sandstone,		
5. Shale,		
4. Coal, upper bench,	2	2
3. Parting,	0	2
2. Coal, lower bench,	0	8
1. Fire clay,		

Chemical analysis and calorific value of Sample 103:

Ultimate.		*Proximate.*	
Carbon	69.58	Moisture	4.62
Hydrogen	5.47	Volatile Comb.	40.95
Oxygen	12.58	Fixed carbon	47.85
Nitrogen	1.30	Ash	6.58
Sulphur	4.49		
Ash	6.58		

Calorific value ..... 7,126 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 104.

Mine of A. W. Smith, Muskingum township, Muskingum county. The sample was cut from a section, about 18 by 5 inches, by B. A. Eisenlohr in August, 1902. A little mud fell into the coal, hence the sample is not first class.

SECTION 104

	Ft.	In.
8. Shale,		
7. False roof (dirty coal),		
6. Coal, upper bench,	1	7
5. Pyrites,	0	3
4. Coal, middle bench,	0	6
3. Parting,	0	2
2. Coal, lower bench,	1	6
1. Fire clay,		

Chemical analysis and calorific value of Sample 104:

Ultimate.		*Proximate.*	
Carbon	70.54	Moisture	5.55
Hydrogen	5.57	Volatile Comb.	40.27
Oxygen	13.77	Fixed carbon	48.95
Nitrogen	1.26	Ash	5.23
Sulphur	3.63		
Ash	5.23		

Calorific value ..... 7,191 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 105.

Mine of A. W. Marshall, section 17, Jackson township, Coshocton county. Very good sample cut from section about 12 by 5 inches by B. A. Eisenlohr in August, 1902. About 20 feet lower is another coal, 4 feet thick, and about 60 feet below the No. 6 seam is still another coal, 18 inches thick. The latter is covered with a fossiliferous and the former with a non-fossiliferous limestone.

SECTION 105

	Ft.	In.
6. Sandstone,		
5. Shale,	0	8
4. Coal, upper bench,	2	9
3. Parting,	0	1
2. Coal, lower bench,	0	11
1. Fire clay,		

Chemical analysis and calorific value of Sample 105:

Ultimate.		*Proximate.*	
Carbon	69.29	Moisture	5.32
Hydrogen	5.50	Volatile Comb.	40.93
Oxygen	13.45	Fixed carbon	47.45
Nitrogen	1.24	Ash	6.30
Sulphur	4.22		
Ash	6.30		

Calorific value ..... 7,086 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 106.

Mine of G. W. Levengood, section 20, Clark township, Coshocton county. Where sample was cut the lower bench is wanting. Excellent sample about 18 by 6 inches and cut by B. A. Eisenlohr in August, 1902.

SECTION 106

	Ft.	In.
4. Sandstone,		
3. Shale,	3	0
2. Coal,	2	5
1. Fire clay,		

Chemical analysis and calorific value of Sample 106:

Ultimate.		*Proximate.*	
Carbon	69.59	Moisture	5.30
Hydrogen	5.50	Volatile Comb.	39.08
Oxygen	13.92	Fixed carbon	49.47
Nitrogen	1.12	Ash	6.15
Sulphur	3.72		
Ash	6.15		

Calorific value ..... 7,084 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 107.

Mine of E. McClure, Keene township, Coshocton county. Sample very good, cut from a section about 24 by 5 inches by B. A. Eisenlohr in August, 1902.

SECTION 107

	Ft.	In.
3. Shale,		
2. Coal,	2	1
1. Fire clay,		

Chemical analysis and calorific value of Sample 107:

Ultimate.		*Proximate.*	
Carbon	70.90	Moisture	5.40
Hydrogen	5.58	Volatile Comb.	39.92
Oxygen	14.02	Fixed carbon	49.60
Nitrogen	1.24	Ash	5.08
Sulphur	3.18		
Ash	5.08		

Calorific value ..... 7,194 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 108.

Mine of Best Coal Company, Franklin township, Coshocton county. Sample fine, cut from section about 12 by 4 inches by B. A. Eisenlohr in August, 1902.

SECTION 108

	Ft.	In.
5. Shale,		
4. Coal, upper bench,	2	10
3. Parting,	0	2
2. Coal, lower bench,	1	4
1. Fire clay,		

Chemical analysis and calorific value of Sample 108:

Ultimate.		*Proximate.*	
Carbon	71.42	Moisture	4.55
Hydrogen	5.41	Volatile Comb.	41.11
Oxygen	12.36	Fixed carbon	48.97
Nitrogen	1.22	Ash	5.59
Sulphur	4.00		
Ash	5.59		

Calorific value ..... 7,269 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 109.

Mine of Charles Fillomlee, Virginia township, Coshocton county. Coal contains numerous pyrite and soot streaks. Sample rather dirty. Cut from a section about 24 by 5 inches by B. A. Eisenlohr in August, 1902.

Chemical analysis and calorific value of Sample 109:

Ultimate.		*Proximate.*	
Carbon	69.49	Moisture	5.12
Hydrogen	5.45	Volatile Comb.	38.99
Oxygen	12.97	Fixed carbon	48.87
Nitrogen	1.20	Ash	7.02
Sulphur	3.87		
Ash	7.02		

Calorific value ..... 7,066 calories.

SECTION 109

	Ft.	In.
5. Shale,		
4. Coal, upper bench,	3	0
3. Parting,	0	1½
2. Coal, lower bench,	0	7
1. Fire clay,		

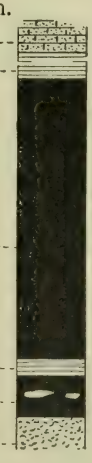
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 110.

Mine of J. P. Patton, Coshocton county. Good sample cut from a section about 18 by 5 inches by B. A. Eisenlohr in August, 1902.

SECTION 110

	Ft.	In.
6. Sandstone,		
5. Shale,	0	3
4. Coal, upper bench,	2	9
3. Parting,	0	2
2. Coal, lower bench,	0	5
1. Fire clay,		



Chemical analysis and calorific value of Sample 110:

Ultimate.		*Proximate.*	
Carbon	61.59	Moisture	5.60
Hydrogen	4.95	Volatile Comb.	34.69
Oxygen	14.23	Fixed carbon	46.43
Nitrogen	1.08	Ash	13.28
Sulphur	4.87		
Ash	13.28		

Calorific value ..... 6,222 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 111.

Mine of W. J. Young, section 24, Linton township, Coshocton county. Fair sample cut from a section about 25 by 5 inches by B. A. Eisenlohr in August, 1902.

SECTION 111

	Ft.	In.
7. Sandstone,		
6. Shale,	0	10
5. Dirty coal,	0	5
4. Coal, upper bench,	2	6
3. Parting,	0	2
2. Coal, lower bench,	0	10
1. Fire clay,		

Chemical analysis and calorific value of Sample 111:

Ultimate.		*Proximate.*	
Carbon	71.34	Moisture	4.37
Hydrogen	5.56	Volatile Comb.	40.97
Oxygen	12.85	Fixed carbon	49.30
Nitrogen	1.28	Ash	5.36
Sulphur	3.61		
Ash	5.36		

Calorific value ..... 7,247 calories.

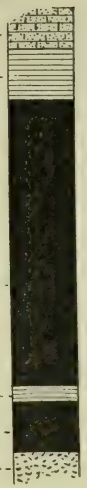
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 112.

Mine of Peter Hammersly, section 2, Linton township, Coshocton county. Sample not very good owing to bad condition of mine. Cut from section about 16 by 7 inches by B. A. Eisenlohr in August, 1902.

SECTION 112

	Ft.	In.
6. Sandstone,		
5. Shale,		
4. Coal, upper bench,	2	10
3. Parting,	0	2
2. Coal, lower bench,	0	6
1. Fire clay,		



Chemical analysis and calorific value of Sample 112:

Ultimate.		*Proximate.*	
Carbon	63.08	Moisture	10.93
Hydrogen	5.37	Volatile Comb.	34.00
Oxygen	21.73	Fixed carbon	48.43
Nitrogen	1.15	Ash	6.64
Sulphur	2.03		
Ash	6.64		

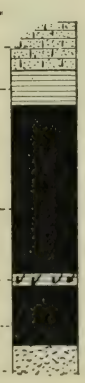
Calorific value ..... 6,133 calories.

SAMPLE AND SECTION 113.

Mine of Peter Henricks, section 20, Oxford township, Coshocton county. New mine, sample taken about 225 feet from entrance. Coal has numerous pyrite bands. Good sample cut from section, about 24 by 5 inches, by B. A. Eisenlohr in August, 1902.

SECTION 113

	Ft.	In.
6. Sandstone,		
5. Shale,		
4. Coal, upper bench,	1	8
3. Pyrites,	0	1½
2. Coal, lower bench,	0	7
1. Fire clay,		



Chemical analysis and calorific value of Sample 113:

Ultimate.		*Proximate.*	
Carbon	72.65	Moisture	4.44
Hydrogen	5.53	Volatile Comb.	40.71
Oxygen	12.48	Fixed carbon	50.40
Nitrogen	1.35	Ash	4.45
Sulphur	3.54		
Ash	4.45		

Calorific value ..... 7,351 calories.

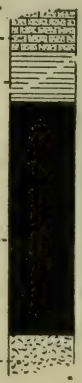
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 114.

Mine of Young Brothers, section 1, Adams township, Coshocton county. Coal has numerous pyrite layers which appear and disappear. Sample not the best. Cut from section about 30 by 4 inches, by B. A. Eisenlohr in August, 1902.

SECTION 114

	Ft.	In.
4. Sandstone,		
3. Shale,	20	0
2. Coal,	2	4
1. Fire clay,		



Chemical analysis nd calorific value of Sample 114:

Ultimate.		*Proximate.*	
Carbon	67.51	Moisture	4.58
Hydrogen	5.40	Volatile Comb.	39.18
Oxygen	11.74	Fixed carbon	47.49
Nitrogen	1.24	Ash	8.75
Sulphur	5.36		
Ash	8.75		

Calorific value ..... 6,878 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 115.

Mine of A. J. Hawk, Jefferson township, Tuscarawas county. Sample not satisfactory. Eight inches of coal were left at the top. Sampled by B. A. Eisenlohr in August, 1902.

SECTION 115

	Ft.	In.
4. Sandstone,		
3. Shale,		
2. Coal,	2	8
1. Fire clay,		

Chemical ahalysis and calorific value of Sample 115:

Ultimate.		*Proximate.*	
Carbon	71.08	Moisture	4.72
Hydrogen	5.53	Volatile Comb.	40.30
Oxygen	12.55	Fixed carbon	49.51
Nitrogen	1.32	Ash	5.47
Sulphur	4.05		
Ash	5.47		

Calorific value ..... 7,199 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 116.

Mine of Troyer & Co., Bucks township, Tuscarawas county. Coal has irregular streaks of pyrite. Sample excellent. Cut from section about 16 by 4 inches, by B. A. Eisenlohr in August, 1902.

SECTION 116

	Ft.	In.
4. Sandstone,		
3. Shale,	15	0
2. Coal,	2	11
1. Fire clay,		

Chemical analysis and calorific value of Sample 116:

Ultimate.		*Proximate.*	
Carbon	70.12	Moisture	5.19
Hydrogen	5.59	Volatile Comb.	40.79
Oxygen	13.51	Fixed carbon	48.15
Nitrogen	1.36	Ash	5.87
Sulphur	3.55		
Ash	5.87		

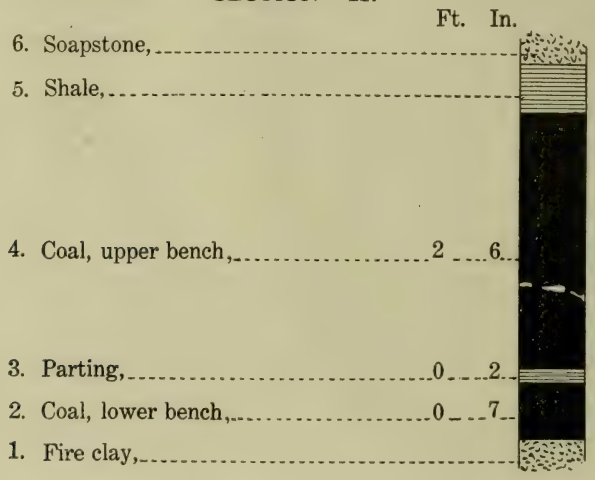
Calorific value ..... 7,122 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 117.

Mine of John S. Baker, section 4, Crawford township, Coshocton county. Good sample cut from section about 14 by 6 inches, by B. A. Eisenlohr in August, 1902.

SECTION 117



Chemical analysis and calorific value of Sample 117:

Ultimate.		*Proximate.*	
Carbon	64.78	Moisture	4.70
Hydrogen	5.23	Volatile Comb.	39.20
Oxygen	11.98	Fixed carbon	44.81
Nitrogen	1.12	Ash	11.29
Sulphur	5.60		
Ash	11.29		

Calorific value ..... 6,594 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 118.

Mine of Adam Miller, section 5, White Eyes township, Coshocton county. Fine sample. Cut from section about 15 by 5 inches, by B. A. Eisenlohr in August, 1902.

SECTION 118

	Ft.	In.
7. Sandstone,		
6. Soapstone,		
5. Shale,	0	6
4. Coal, upper bench,	2	9
3. Parting,	0	1½
2. Coal, lower bench,	0	11
1. Fire clay,		

Chemical analysis and calorific value of Sample 118:

Ultimate.		*Proximate.*	
Carbon	67.41	Moisture	5.32
Hydrogen	5.32	Volatile Comb.	37.39
Oxygen	13.13	Fixed carbon	48.69
Nitrogen	1.18	Ash	8.60
Sulphur	4.36		
Ash	8.60		

Calorific value ..... 6,828 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 119.

Mine of Michael Zalmer, section 24, Walnut Creek township, Holmes county. The coal in this mine is more or less red and weathered. Sample cut from section about 14 by 7 inches, by B. A. Eisenlohr in August, 1902.

Chemical analysis and calorific value of Sample 119:

Ultimate.		*Proximate.*	
Carbon	70.62	Moisture	7.31
Hydrogen	5.42	Volatile Comb.	34.92
Oxygen	17.31	Fixed carbon	53.56
Nitrogen	1.44	Ash	4.21
Sulphur	1.00		
Ash	4.21		

Calorific value ..... 6,952 calories.

SECTION 119

	Ft.	In.
3. Shale,		
2. Coal,	2	6
1. Fire clay,		

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 120.

Mine of Lewis McFarland, section 24, White Eyes township, Coshocton county. Good sample cut from section about 14 by 4 inches, by B. A. Eisenlohr in August, 1902.

SECTION 120

	Ft.	In.
9. Sandstone,		
8. Soapstone,	5′—0″ to 12	0
7. False roof (dirty coal),	0	6
6. Coal, upper bench,	2	0
5. Pyrites,	0	1
4. Coal, middle bench,	1	0
3. Parting,	0	2
2. Coal, lower bench,	1	2
1. Fire clay,		

Chemical analysis and calorific value of Sample 120:

Ultimate.		*Proximate.*	
Carbon	70.94	Moisture	4.50
Hydrogen	5.53	Volatile Comb.	38.73
Oxygen	12.63	Fixed carbon	50.80
Nitrogen	1.30	Ash	5.97
Sulphur	3.63		
Ash	5.97		

Calorific value ..... 7,173 calories.

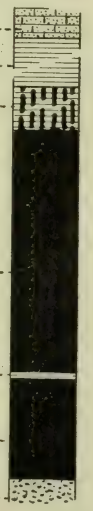
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 121.

Mine of Timothy Sewell, Dover township, Tuscarawas county. Coal quite free from pyrite except in the parting. Good sample, cut from section about 12 by 7 inches, by B. A. Eisenlohr in August, 1902.

SECTION 121

	Ft.	In.
7. Sandstone,		
6. Shale,	12	0
5. Bone coal,	0	5
4. Coal, upper bench,	2	5
3. Parting,	0	1
2. Coal, lower bench,	1	0
1. Fire clay,		



Chemical analysis and calorific value of Sample 121:

Ultimate.		*Proximate.*	
Carbon	72.13	Moisture	3.52
Hydrogen	5.41	Volatile Comb.	40.25
Oxygen	12.00	Fixed carbon	50.22
Nitrogen	1.28	Ash	6.01
Sulphur	3.17		
Ash	6.01		

Calorific value ..... 7,297 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 122.

Mine of Joseph Shilling, Dover township, Tuscarawas county. Good sample, cut from section about 14 by 6 inches, by B. A. Eisenlohr in August, 1902.

SECTION *122*

	Ft.	In.
3. Coal, upper bench,	2	3
2. Pyrites,	0	2
1. Coal, lower bench,	1	3

Chemical analysis and calorific value of Sample 122:

Ultimate.		*Proximate.*	
Carbon	67.54	Moisture	4.94
Hydrogen	5.14	Volatile Comb.	36.20
Oxygen	12.33	Fixed carbon	49.36
Nitrogen	1.30	Ash	9.50
Sulphur	4.19		
Ash	9.50		

Calorific value ..... 6,856 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 123.

Mine of East Goshen Coal Company, section 12, Goshen township, Tuscarawas county. Coal has considerable pyrite, especially in the lower and upper benches. Good sample cut from section about 14 by 4 inches. Sampled by B. A. Eisenlohr in August, 1902.

Chemical analysis and calorific value of Sample 123:

Ultimate.		*Proximate.*	
Carbon	70.26	Moisture	3.51
Hydrogen	5.45	Volatile Comb.	41.60
Oxygen	10.82	Fixed carbon	47.20
Nitrogen	1.22	Ash	7.69
Sulphur	4.56		
Ash	7.69		

Calorific value ..... 7,153 calories.

SECTION 123

	Ft.	In.
7. Soapstone,		
6. Coal, upper bench,	2	2
5. Parting,	0	1½
4. Coal, middle bench,	1	0
3. Parting,	0	2½
2. Coal, lower bench,	1	3
1. Fire clay,		

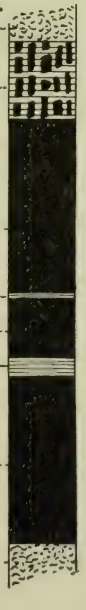
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 124.

Mine of Medville & Goshen Coal Company, Warwick township, Tuscarawas county. Sample fair, cut from section about 12 by 5 inches, by B. A. Eisenlohr in August, 1902.

SECTION 124

	Ft.	In.
8. Soapstone,		
7. Bone coal,	0	9
6. Coal, upper bench,	1	9
5. Parting,	0	½
4. Coal, middle bench,	0	7
3. Parting,	0	2½
2. Coal, lower bench,	1	8
1. Fire clay,		



Chemical analysis and calorific value of Sample 124:

Ultimate.		*Proximate.*	
Carbon	72.45	Moisture	4.10
Hydrogen	5.57	Volatile Comb.	41.64
Oxygen	12.10	Fixed carbon	49.05
Nitrogen	1.42	Ash	5 21
Sulphur	3.25		
Ash	5.21		

Calorific value ..... 7,331 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 125.

Mine of Valentine Lieser, section 24, Lawrence township, Tuscarawas county. Sample contains some dirt and so is not satisfactory. Was cut from a section about 18 by 4 inches, by B. A. Eisenlohr in August, 1902.

SECTION 125

	Ft.	In.
8. Sandstone,		
7. Shale,	17	0
6. Coal, upper bench,	2	1
5. Pyrites,	0	½
4. Coal, middle bench,	0	5
3. Parting,	0	½
2. Coal, lower bench,	0	5
1. Fire clay,		

Chemical analysis and calorific value of Sample 125:

Ultimate.		*Proximate.*	
Carbon	67.59	Moisture	4.69
Hydrogen	5.30	Volatile Comb.	39.57
Oxygen	12.11	Fixed carbon	46.68
Nitrogen	1.24	Ash	9.06
Sulphur	4.70		
Ash	9.06		

Calorific value ..... 6,881 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 126.

Mine of Tuscarawas C. & I. Company, near center of Sandy township, Tuscarawas county. Good sample cut from section about 19 by 5 inches. Sampled by B. A. Eisenlohr in August, 1902.

SECTION 126

	Ft.	In.
5. Soapstone,		
4. Coal, upper bench,	1	10
3. Pyrites,	0	1
2. Coal, lower bench,	2	2
1. Fire clay,		

Chemical analysis and calorific value of Sample 126:

Ultimate.		*Proximate.*	
Carbon	70.45	Moisture	4.92
Hydrogen	5.40	Volatile Comb.	38.13
Oxygen	12.92	Fixed carbon	49.91
Nitrogen	1.28	Ash	7.04
Sulphur	2.91		
Ash	7.04		

Calorific value .....7,082 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 127.

Mine of Somerdale Coal Company, section 9, Fairfield township, Tuscarawas county. Good sample, cut from section about 10 by 5 inches. Sampled by B. A. Eisenlohr in August, 1902.

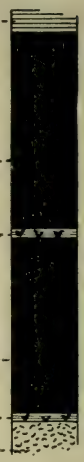
Chemical analysis and calorific value of Sample 127:

Ultimate.		*Proximate.*	
Carbon	70.80	Moisture	4.66
Hydrogen	5.48	Volatile Comb.	39.25
Oxygen	12.94	Fixed carbon	49.87
Nitrogen	1.28	Ash	6.22
Sulphur	3.28		
Ash	6.22		

Calorific value .....7,097 calories.

SECTION 127

	Ft.	In.
6. Shale,	10	0
5. Coal, upper bench,	1	11
4. Pyrites,	0	1
3. Coal, lower bench,	1	9
2. Pyrites,	0	1
1. Fire clay,		



MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 128.

Mine of Jacob Groh, section 17, Auburn township, Tuscarawas county. Top coal is always rejected. The lower bench contains occasional pyrite nuggets, which are always rejected. Excellent sample, cut from section about 16 by 5 inches, by B. A. Eisenlohr in September, 1902.

SECTION 128

	Ft.	In.
9. Slate,		
8. Top coal,	0	2½
7. Shale,	0	2
6. Coal, upper bench,	2	6
5. Parting,	0	1
4. Coal, middle bench,	0	5
3. Pyrites,	0	2
2. Coal, lower bench,	0	5
1. Fire clay,		

Chemical analysis and calorific value of Sample 128:

		Proximate.	
Carbon	69.39	Moisture	4.30
Hydrogen	5.41	Volatile Comb.	40.07
Oxygen	12.32	Fixed carbon	48.00
Nitrogen	1.28	Ash	7.63
Sulphur	3.97		
Ash	7.63		

Calorific value ..... 7,001 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 129.

Mine of American Sheet Steel Company, Union township, Tuscarawas county. Lower and middle benches are not defined throughout but frequently run together. The mine was muddy and some dirt may have gotten in the coal. Sample cut from a section about 15 by 4 inches, by B. A. Eisenlohr in September, 1902.

SECTION 129

	Ft.	In.
8. Sandstone,		
7. Soapstone,	3	0
6. Coal, upper bench,	2	0
5. Pyrites,	0	2
4. Coal, middle bench,	1	0
3. Parting,	0	½
2. Coal, lower bench,	0	11
1. Fire clay,		

Chemical analysis and calorific value of Sample 129:

Ultimate.		*Proximate.*	
Carbon	72.30	Moisture	3.81
Hydrogen	5.41	Volatile Comb.	38.71
Oxygen	11.68	Fixed carbon	51.47
Nitrogen	1.36	Ash	6.01
Sulphur	3.24		
Ash	6.01		

Calorific value ..... 7,306 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 130.

Mine of Cyrus Kilpatrick, Mill township, Tuscarawas county. The sulphur band is regular but the other partings irregular. Excellent sample cut from section about 15 by 5 inches, by B. A. Eisenlohr in September, 1902.

SECTION 130

	Ft.	In.
7. Bastard rock,		
6. Coal,	0	6
5. Parting,	0	½
4. Coal, middle bench,	1	4
3. Pyrites,	0	2
2. Coal, lower bench,	1	2
1. Fire clay,		

Chemical analysis and calorific value of Sample 130:

Ultimate.		*Proximate.*	
Carbon	70.31	Moisture	3.78
Hydrogen	5.26	Volatile Comb.	38.27
Oxygen	10.96	Fixed carbon	49.53
Nitrogen	1.22	Ash	8.42
Sulphur	3.83		
Ash	8.42		

Calorific value ..... 7,101 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 131.

Mine of Solomon Stocker, near Gnadenhutten, Tuscarawas county. The dirty coal above the upper bench was rejected. Generally it is not mined. Good sample cut from section about 18 by 5 inches, by B. A. Eisenlohr in September, 1902.

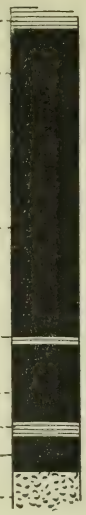
Chemical analysis and calorific value of Sample 131:

Ultimate.		*Proximate.*	
Carbon	68.77	Moisture	3.41
Hydrogen	5.23	Volatile Comb.	39.73
Oxygen	10.44	Fixed carbon	47.48
Nitrogen	1.30	Ash	9.38
Sulphur	4.88		
Ash	9.38		

Calorific value ..... 6,971 calories.

SECTION 131

	Ft.	In.
8. Shale,		
7. Dirty coal,	0	9
6. Coal, upper bench,	2	4
5. Pyrites,	0	1
4. Coal, middle bench,	0	9
3. Pyrites,	0	2
2. Coal, lower bench,	0	4
1. Fire clay,		



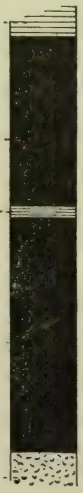
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 132.

Mine of Somers Coal Company, near Sherrodsville, Carroll county. Coal reached by a shaft 80 feet deep. Excellent sample cut from section about 20 by 3 inches. Sampled by B. A. Eisenlohr in September, 1902.

SECTION 132

	Ft.	In.
5. Shale,		
4. Coal, upper bench,	1	8
3. Pyrites,	0	1½
2. Coal, lower bench,	2	4
1. Fire clay,		



Chemical analysis and calorific value of Sample 132:

Ultimate.		*Proximate.*	
Carbon	71.99	Moisture	3.76
Hydrogen	5.36	Volatile Comb.	39.11
Oxygen	11.40	Fixed carbon	50.34
Nitrogen	1.40	Ash	6.79
Sulphur	3.06		
Ash	6.79		

Calorific value ..... 7,238 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 133.

Mine of Jacob Stonebrook, near Newcomerstown, Tuscarawas county. Coal is quite dirty. Sample excellent. Cut from section about 20 by 4 inches, by B. A. Eisenlohr in September, 1902.

SECTION 133

	Ft.	In.
9. Shale,		
8. Coal,	0	12
7. Parting,	0	½
6. Coal,	1	0
5. Dirty coal and pyrites,	0	4
4. Coal,	0	3
3. Coal and pyrites,	0	6
2. Coal,	0	4
1. Fire clay,		

Chemical analysis and calorific value of Sample 133:

Ultimate.		*Proximate.*	
Carbon	70.02	Moisture	3.45
Hydrogen	5.30	Volatile Comb.	40.02
Oxygen	10.53	Fixed carbon	48.86
Nitrogen	1.26	Ash	7.67
Sulphur	5.22		
Ash	7.67		

Calorific value ..... 7,135 calories.

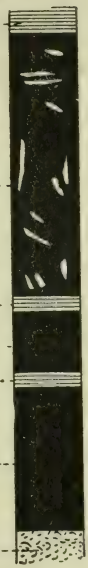
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 134.

West Goshen Mine, York township, Tuscarawas county. Coal dirty, especially the middle bench. Lower parting sometimes absent. Sample excellent. Cut from section about 14 by 4 inches, by B. A. Eisenlohr in September, 1902.

SECTION 134

	Ft.	In.
7. Shale,		
6. Coal, upper bench,	2	7
5. Parting,	0	2
4. Coal, middle bench,	0	7
3. Parting,	0	2
2. Coal, lower bench,	1	5
1. Fire clay,		



Chemical analysis and calorific value of Sample 134:

Ultimate.		*Proximate.*	
Carbon	71.13	Moisture	3.18
Hydrogen	5.50	Volatile Comb.	43.56
Oxygen	11.04	Fixed carbon	46.33
Nitrogen	1.28	Ash	6.93
Sulphur	4.12		
Ash	6.93		

Calorific value ..... 7,305 calories.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 135.

Mine of Whitacre Fire-proofing Company, Waynesburg, Tuscarawas county. Sample cut from a fresh face well under the hill. The coal was wet and appeared inferior from top to bottom. Sampled by D. D. Condit in December, 1907. The clay below the coal is used in making the fire-proofing. It is removed first and then the coal shot down.

Chemical analysis and calorific value of Sample 135:

Ultimate.		*Proximate.*	
Carbon	68.94	Moisture	6.66(a)
Hydrogen	5.37	Volatile Matter	36.24
Oxygen	13.61	Fixed carbon	48.88
Nitrogen	1.20	Ash	8.22
Sulphur	2.66		
Ash	8.22		
	100.00		100.00

Calorific value ..... 6,977 calories.

(a) Moisture in the air-dried sample from 2½ to 3 per cent.

SECTION 135

	Ft.	In.
5. Shale,		
4. Coal,	1	1
3. Clay and pyrites,	1	1½
2. Coal,	1	8½
1. Fire clay,		

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 136.

Mine of J. W. Stout, Alliance, Stark county. Sample consists of a section 6 by 4 inches and was cut by D. D. Condit in December, 1907.

SECTION 136

	Ft.	In.
8. Shale,		
7. Bone coal,	0	1
6. Coal,	0	4½
5. Pyrites,	0	½
4. Coal,	0	5
3. Pyrites, persistent,	0	1½
2. Coal,	1	9
1. Fire clay,		

Chemical analysis and calorific value of Sample 136:

Ultimate.		*Proximate.*	
Carbon	71.82	Moisture	5.99(a)
Hydrogen	5.56	Volatile Matter	39.05
Oxygen	12.86	Fixed carbon	50.14
Nitrogen	1.33	Ash	4.82
Sulphur	3.61		
Ash	4.82		
	100.00		100.00

Calorific value ..... 7,314 calories.

(a) Moisture in the air-dried sample from 2½ to 3 per cent.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 137.

Mine of W. J. Blackford at mouth of Dry Run, East Liverpool, Columbiana county. Sample consists of a section 7 by 4 inches and was cut by D. D. Condit in December, 1907.

SECTION 137

	Ft.	In.
6. Shale,		
5. Dirty coal,	0	4
4. Coal,	1	6
3. Shale,	0	3
2. Impure coal,	0	4
1. Fire clay,		

Chemical analysis and calorific value of Sample 137:

Ultimate.		*Proximate.*	
Carbon	77.06	Moisture	3.60(a)
Hydrogen	5.46	Volatile Matter	36.16
Oxygen	9.74	Fixed carbon	55.64
Nitrogen	1.38	Ash	4.60
Sulphur	1.76		
Ash	4.60		
	100.00		100.00

Calorific value ..... 7,789 calories.

(a) Moisture in the air-dried sample about 2%.

MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 138.

Mine of the Somerdale Coal Company, Somerdale, Tuscarawas county. Coal rather moist. Sample consists of a section 6 by 3 inches and was cut by D. D. Condit in December, 1907.

Chemical analysis and calorific value of Sample 138:

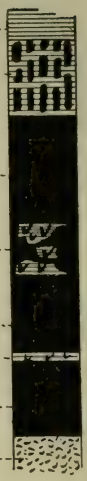
Ultimate.		*Proximate.*	
Carbon	71.29	Moisture	7.15(a)
Hydrogen	5.64	Volatile Matter	38.34
Oxygen	14.66	Fixed carbon	49.95
Nitrogen	1.23	Ash	4.56
Sulphur	2.62		
Ash	4.56		
	100.00		100.00

Calorific value ..... 7,194 calories.

(a) Moisture in the air-dried sample from 2½ to 3 per cent.

SECTION 138

	Ft.	In.
8. Shale with nodular ore,		
7. Bone coal and pyrites,	0	9
6. Coal,	1	1
5. Coal and pyrites,	0	6
4. Coal,	0	9
3. Clay and pyrites,	0	1
2. Coal,	0	8½
1. Fire clay,		



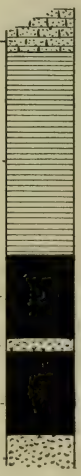
MIDDLE KITTANNING COAL.

SAMPLE AND SECTION 139.

McGinty mine, section 24, Nimishillen township, Stark county. Sample consists of a section 6 by 3 inches. The clay below the coal is also used.

SECTION 139

	Ft.	In.
6. Sandstone,		
5. Shale and nodular ore,	2	0
4. Coal,	0	10
3. Clay,	0	1½
2. Coal,	1	10
1. Fire clay,		



Chemical analysis and calorific value of Sample 139:

Ultimate.		*Proximate.*	
Carbon	66.92	Moisture	5.65
Hydrogen	5.29	Volatile Matter	38.51
Oxygen	12.39	Fixed carbon	45.76
Nitrogen	1.19	Ash	10.08
Sulphur	4.13		
Ash	10.08		
	100.00		100.00

Calorific value .....6,868 calories.

(a) Moisture in the air-dried sample from 2½ to 3 per cent.

CHAPTER VII.

THE UPPER FREEPORT OR NO. 7 COAL.[1]

This seam like the Middle Kittanning can be traced across the state. It is much less persistent in thickness, however, than the Middle Kittanning seam, and is of correspondingly smaller value. The best deposits of the coal are found in the eastern and northeastern parts of the state. The Cambridge field which included parts of Guernsey and Noble counties forms one of the most valuable coal deposits in the state, its output in 1906 being in excess of 3,000,000 tons.

The analyses reported in this work, however, do not include the Cambridge field or the territory to the northeast and hence no further reference will be made to it.

In the northeastern part of Lawrence and the adjacent part of Gallia county is a deposit of importance. It is known as the Waterloo field from the little village of that name. Thus far the coal has been mined for local use only, owing to the lack of transportation facilities. When the latter is provided the field may become a large producer. The sections and analyses which follow correctly show its thickness, structure and composition.

Between this field and the Cambridge the seam is irregular. Occasionally banks are opened by farmers, but mines for shipment are very scarce.

UPPER FREEPORT COAL.

SAMPLE AND SECTION 140.

Cooper's Mine, section 24 or 25, Symmes township, Lawrence county. Sample was taken from lower bench only. Good. sample. Taken by E. E. Somermeier in August, 1901.

Chemical analysis and calorific value of Sample 140:

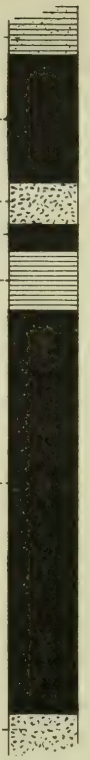
Ultimate.		*Proximate.*	
Carbon	67.09	Moisture	7.13
Hydrogen	5.33	Volatile Comb.	33.65
Oxygen	16.08	Fixed carbon	50.31
Nitrogen	1.28	Ash	8.91
Sulphur	1.31		
Ash	8.91		

Calorific value ..... 6,716 calories.

[1] For method of sampling see Chapter IX.

SECTION 140

	Ft.	In.
7. Clay and shale,		
6. Coal, upper bench,	1	3
5. Clay,	0	5
4. Coal,	0	3
3. Shale,	0	7
2. Coal, lower bench,	4	0
1. Fire clay,		



UPPER FREEPORT COAL.

SAMPLE AND SECTION 141.

Mine of G. W. Peach, section 23, Symmes township, Lawrence county. Sample includes both benches. Sampled by E. E. Somermeier in August, 1901.

Chemical analysis and calorific value of Sample 141:

Ultimate.		*Proximate.*	
Carbon	66.88	Moisture	8.77
Hydrogen	5.32	Volatile Comb.	31.70
Oxygen	17.08	Fixed carbon	50.82
Nitrogen	1.25	Ash	8.71
Sulphur	0.76		
Ash	8.71		

Calorific value ..... 6,586 calories.

SECTION 141

	Ft.	In.
3. Coal, upper bench,	0	5
2. Clay,	1	2
1. Coal, lower bench,	3	9

UPPER FREEPORT COAL.

SAMPLE AND SECTION 142.

Sander's Mine, section 17, Walnut township, Gallia county. Lower bench only sampled, the upper bench not mined. Mine had not been worked for three years, but coal appeared fresh. The surface of the coal was cut off before sampling. Sampled by E. E. Somermeier in August, 1902.

SECTION 142

	Ft.	In.
4. Coal, upper bench,		
3. Shale, coal, and clay,	0	9½
2. Coal, lower bench,	2	10
1. Fire clay,		

Chemical analysis and calorific value of Sample 142:

Ultimate.		*Proximate.*	
Carbon	63.48	Moisture	7.62
Hydrogen	5.19	Volatile Comb.	32.85
Oxygen	15.85	Fixed carbon	47.14
Nitrogen	1.28	Ash	12.39
Sulphur	1.81		
Ash	12.39		

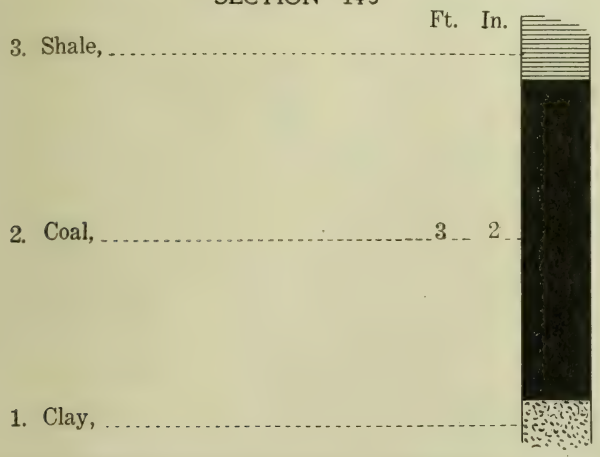
Calorific value ..... 6,371 calories.

UPPER FREEPORT COAL.

SAMPLE AND SECTION 143.

Mine of William Sneed, section 26 or 27, Symmes township, Lawrence county. One bench only sampled, that being the only part mined. Fresh face of coal. Sampled by E. E. Somermeier in August, 1901.

SECTION 143



Chemical analysis and calorific value of Sample 143:

Ultimate.		*Proximate.*	
Carbon	64.90	Moisture	8.38
Hydrogen	5.18	Volatile Comb.	31.45
Oxygen	16.72	Fixed carbon	50.08
Nitrogen	1.27	Ash	10.09
Sulphur	1.84		
Ash	10.09		

Calorific value ..... 6,497 calories.

UPPER FREEPORT COAL.

SAMPLE AND SECTION 144.

Walter Rose Mine, section 21, Aid township, Lawrence county. Good sample of lower bench, the upper bench not mined. Sample cut by E. E. Somermeier in August, 1901.

SECTION 144

	Ft.	In.
3. Coal, upper bench,	1	4
2. Clay,	0	7
1. Coal, lower bench,	2	6

Chemical analysis and calorific value of Sample 144:

Ultimate.		*Proximate.*	
Carbon	63.03	Moisture	7.85
Hydrogen	5.09	Volatile Comb.	32.90
Oxygen	15.79	Fixed carbon	47.07
Nitrogen	1.25	Ash	12.18
Sulphur	2.66		
Ash	12.18		

Calorific value ..... 6,305 calories.

UPPER FREEPORT COAL.

SAMPLE AND SECTION 145.

Haskin's Mine, section 36, Aid township, Lawrence county. Sample taken from lower bench only, the upper bench not mined. Sampled by E. E. Somermeier in August, 1901.

Chemical analysis and calorific value of Sample 145:

Ultimate.		*Proximate.*	
Carbon	66.94	Moisture	8.37
Hydrogen	5.21	Volatile Comb.	31.80
Oxygen	17.02	Fixed carbon	51.60
Nitrogen	1.31	Ash	8.23
Sulphur	1.29		
Ash	8.23		

Calorific value ..... 6,596 calories.

SECTION 145

	Ft.	In.
4. Coal, upper bench, not mined,	1	0
3. Shales, very hard,	1	0
2. Coal, lower bench,	3	2
1. Fire clay,		

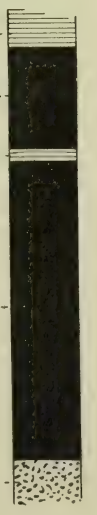
UPPER FREEPORT COAL.

SAMPLE AND SECTION 146.

Mine of Thomas Bennett, section 35, Aid township, Lawrence county. Both benches included in sample. Sampled by E. E. Somermeier in August, 1901.

SECTION 146

	Ft.	In.
5. Shale,		
4. Coal, upper bench,	1	0
3. Shale,	0	1½
2. Coal, lower bench,	3	0
1. Fire clay,		



Chemical analysis and calorific value of Sample 146:

Ultimate.		*Proximate.*	
Carbon	65.20	Moisture	8.45
Hydrogen	5.10	Volatile Comb.	31.25
Oxygen	16.21	Fixed carbon	49.02
Nitrogen	1.28	Ash	11.28
Sulphur	0.93		
Ash	11.28		

Calorific value .....6,405 calories.

UPPER FREEPORT COAL.

SAMPLE AND SECTION 147.

Mine of Frank Kitts, section 16, Lawrence township, Lawrence county. Lower bench only sampled, the upper bench not worked. Sampled by E. E. Somermeier in August, 1901.

SECTION 147

	Ft.	In.
5. Sandstone and slate,		
4. Coal, upper bench, not mined,	1	2
3. Clay,	0	7
2. Coal, lower bench,	2	2
1. Fire clay,		

Chemical analysis and calorific value of Sample 147:

Ultimate.		*Proximate.*	
Carbon	65.03	Moisture	7.20
Hydrogen	5.03	Volatile Comb.	32.25
Oyxgen	15.69	Fixed carbon	49.88
Nitrogen	1.25	Ash	10.67
Sulphur	2.33		
Ash	10.67		

Calorific value .....6,556 calories.

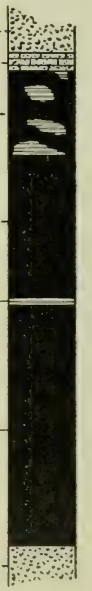
UPPER FREEPORT COAL.

SAMPLE AND SECTION 148.

Mine of Blue Rock Coal Company, Harrison township, Muskingum county. Good sample cut from a section 12 by 7 inches, by B. A. Eisenlohr in July, 1902.

SECTION 148

	Ft.	In.
7. Soapstone,		
6. Sandstone,		
5. Cannel coal, shaly,	9 to 11	0
4. Coal, upper bench,	1	5
3. Parting,	0	1
2. Coal, lower bench,	2	4
1. Fire clay,		



Chemical analysis and calorific value of Sample 148:

Ultimate.		*Proximate.*	
Carbon	67.74	Moisture	4.89
Hydrogen	5.53	Volatile Comb.	42.35
Oxygen	13.42	Fixed carbon	44.98
Nitrogen	1.17	Ash	7.78
Sulphur	4.36		
Ash	7.78		

Calorific value ..... 6,944 calories.

UPPER FREEPORT COAL.

SAMPLE AND SECTION 149.

Mine of Maynard Bros., Brush Creek township, Muskingum county. Sample fair. Cut from section 12 by 4 inches, by B. A. Eisenlohr in August, 1902.

SECTION 149

	Ft.	In.
5. Shale,		
4. Coal, upper bench,	1	4
3. Pyrites,	0	1½
2. Coal, lower bench,	2	7
1. Fire clay,		

Chemical analysis and calorific value of Sample 149:

Ultimate.		*Proximate.*	
Carbon	68.27	Moisture	4.72
Hydrogen	5.55	Volatile Comb.	43.47
Oxygen	12.30	Fixed carbon	44.25
Nitrogen	1.32	Ash	7.56
Sulphur	5.00		
Ash	7.56		

Calorific value ..... 7,046 calories.

UPPER FREEPORT COAL.

SAMPLE AND SECTION 150.

Zanesville Coal Company's Mine, Wayne township, Muskingum county. Sample fair. Cut from a section about 12 by 4 inches, by B. A. Eisenlohr in August, 1902.

Chemical analysis and calorific value of Sample 150:

Ultimate.		*Proximate.*	
Carbon	64.81	Moisture	5.11
Hydrogen	5.11	Volatile Comb.	35.50
Oxygen	12.39	Fixed carbon	46.79
Nitrogen	1.25	Ash	12.60
Sulphur	3.84		
Ash	12.60		

Calorific value ..... 6,558 calories.

SECTION 150

	Ft.	In.
7. Sandstone,		
6. Soapstone,	4	0
5. Coal, upper bench,	1	8
4. Parting,	0	1
3. Coal, hard and flinty,	1	10
2. Coal, lower bench,	2	2
1. Fire clay,		

UPPER FREEPORT COAL.

SAMPLE AND SECTION 151.

Mine of Wm. Darr, section 22, Clark township, Coshocton county. The upper bench only is mined, and the sample was cut from this. The sample measured about 22 by 4 inches and was cut by B. A. Eisenlohr in August, 1902.

SECTION 151

	Ft.	In.
6. Soapstone,		
5. Impure coal,	0	5
4. Coal, upper bench,	2	4
3. Parting,	0	2
2. Coal, lower bench,	0	6
1. Fire clay,		

Chemical analysis and calorific value of Sample 151:

Ultimate.		*Proximate.*	
Carbon	72.72	Moisture	6.40
Hydrogen	5.67	Volatile Comb.	37.92
Oxygen	15.16	Fixed carbon	52.49
Nitrogen	1.25	Ash	3.19
Sulphur	2.01		
Ash	3.19		

Calorific value .....7,325 calories.

CHAPTER VIII.

INTERPRETATION OF THE CHEMICAL AND PHYSICAL TESTS OF COAL.

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The investigation of the coals of Ohio, the results of which are published in this volume, contemplated among other things a complete series of the proximate and ultimate analyses of samples representing the various seams together with the determination of their calorific values and in some cases experiments on their coking properties. As the purification of coal by washing is of growing importance, some experiments were also made on the separation of the coals along the lines of specific gravity, to obtain data of service in determining the adaptability of certain seams to this method of improvement. Complete records were kept of the location, geological position and character of the seam where the samples were taken, and are discussed in the foregoing chapters of the report.

The laboratory work was all done in the Department of Metallurgy and Mineralogy of the Ohio State University by Professor Somermeier and his assistants. The methods used are fully discussed in Professor Somermeier's chapter upon this subject. The present chapter will deal with the meaning of the results obtained and their use in giving information both to the seller and user of the coals covered by the investigation.

In order to properly discuss this part of the work, it will be necessary to briefly review the general nature and character of coal considered as a fuel. It is a matter of common knowledge that coal is the product produced by the alteration and concentration of woody fiber and other products of vegetation when buried out of contact with air. The nature of the organic matter as affected by the kind of vegetation is probably of importance as affecting the properties of the coal, as is also the extent of the alteration to which it has been subjected since its deposition.

In considering a particular coal seam there are several items which are closely related to the geological conditions existing during its formation, such as the nature of the soil on which the coal forests grew, the drainage, water currents, etc., and the extent of the disturbance of the strata occurring subsequently to the covering of the deposits. These matters are primarily subjects for discussion by the geologist. They influence the occurrence of partings and seams, the percentage and kind of ash in the fuel, and may be local or general in their effects.

From the standpoint of their character and value as fuels coals may be considered as composed of three main constitutents:

(1) Water, or "moisture," as it is designated in the analysis.
(2) The "combustible organic matter" of the coal representing the products of the vegetation purely.
(3) The mineral impurities which produce the ash and are accountable for more or less of the sulphur, phosphorus, and other deleterious substances affecting the use of the coal.

Different seams of coal show marked variation in the relative proportions of these constituents, and in the way in which the mineral impurities are intermixed or distributed in the seam. In regard to the second and third items, the nature of the material itself is subject to differences in the different seams or in the same seam in different localities.

(1) The water or moisture in a coal may be considered as of two kinds: First, water present mechanically but in no sense in combination with the fuel, such water as would be retained in the coal if it had been rained upon or in any other way exposed to addition of water. This mechanically held water is frequently present in samples of coal taken for commercial purposes and is always present in samples of coal taken from coal washers. The amount of water that may be mechanically held by coal is greatly influenced by the fineness of the material, lump coal retaining in this mechanical way but a small percentage of water.

A sample of domestic egg coal ranging in size from $1\frac{1}{4}$ inch to $3\frac{1}{4}$ inch after being taken from a washer and allowed to drain for twenty-four hours in the bins showed an air-drying loss of $2\frac{1}{2}$ per cent. A carload of the slack of the same coal, $\frac{5}{8}$-inch and under, after the same treatment showed an air-drying loss of 10.2%. This shows that the fine slack coal retained about four times as much water as the larger screened coal. As some of the loss on air-drying was possibly due to water in other conditions, it is probable that the difference in the amount of water retained mechanically was even greater than shown by the foregoing results. In the coal samples taken from the mine probably but little of the water is in this purely mechanical condition unless the sample has been wet or taken from a wet face.

The second condition in which the water occurs in the coal is that in which it is retained with some degree of affinity, but is expelled easily by drying either in the air at ordinary temperatures or at a temperature but little exceeding the boiling point of water. It is impossible to draw a sharp line between the water in coal held mechanically and this latter form of moisture. The two run into each other to a certain extent. Coal freshly mined usually contains considerable water which will dry out of it rapidly if the coal is broken up to one-half inch size and then exposed to the air at ordinary temperatures.

Extended experiments have shown that a sample of crushed coal exposed to the air will, after a time, reach a condition in which an increase in the moisture present in the air will cause the coal to re-absorb moisture and show a larger percentage of water while a reduction of the percentage of moisture in the air will be followed by a corresponding drop in the percentage of moisture retained by the coal. Coal that has reached such a condition of equilibrium for one degree of fineness may take another condition of equilibrium if it is reduced to a finer powder.

If coal is finely powdered, and then heated to 105°C. in dry air, the free water present as such may be considered as all expelled. This does not mean that the coal on higher heating will not give off more water but that when the coal is heated to this temperature, it reaches a condition of equilibrium which is practically constant for the same coal. The water expelled from the coal at this temperature is what is reported and considered in an analysis as the moisture in the coal. Water retained by the coal under these conditions is in a sufficiently close combination with the coal to be entitled to be considered as an integral part of the coal and cannot be expelled without decomposition of some of the other ingredients. Coal which has been pulverized and dried at this temperature is designated as "dry coal" and so considered in the discussion of the fuels.

In many of the samples tested in the work determinations have been made of the loss on "air drying." This loss corresponds roughly to the water loosely retained in the coal and which would be dried out of it when the coal stands exposed to the atmosphere for some time. The figure is by no means to be taken as having any close meaning as its value will depend considerably on the dryness of the air and the fineness of the coal. The moisture reported in the analysis is the moisture present in the sample of coal as received in the laboratory and is probably less than the percentage of moisture in the coal as it would be if freshly mined, except in those samples where the air drying loss was determined and the analysis corrected to the sample as taken.

(2) The combustible organic matter in the coal. When a sample of coal is burned completely there is left the inorganic ash and the sum of this ash and the moisture present in the coal is frequently considered as the non-combustible portion of the fuel, and the difference between the sum of these amounts and the total amount of coal assumed to be the combustible or fuel portion of the coal.

A little consideration will show that this method of calculation is not correct. The ash stands, not for the mineral matter as it exists in the coal, but for what remains after that mineral matter has been exposed to the effect of oxygen and a high temperature. For example if the coal should contain iron carbonate, the iron would be left in the ash as sesquioxide, involving a considerable loss in weight due to the expulsion of the carbon dioxide. Iron pyrites, usually present in coal, appears in the

ash as iron oxide, the sulphur being largely expelled as sulphur dioxide with a loss in weight of the mineral residue from the expulsion of sulphur which is partially compensated for by the weight of the oxygen absorbed in the change. In this way eight parts of pyrites in the coal will appear as five parts of oxide of iron in the ash. Coals usually contain slate and clay. These hold water which is only expelled at a red heat. This is a source of error if the ash is taken as equivalent to the mineral matter. It is obvious, therefore, that the method of determining the combustible or organic portion of the coal by subtracting the ash plus the moisture from the total weight of the coal is defective and liable to be misleading, the results being only an approximation to the truth, the error increasing with the weight of ash and sulphur present.

A more accurate determination of the total amount of the combustible matter in the coal may usually be obtained from the ultimate analysis, in which the actual amounts of carbon, hydrogen, nitrogen and sulphur present are determined. In the absence of carbonates, which are rarely found in more than very small amounts in coals, the carbon in the coal may be taken as practically wholly derived from organic and combustible sources.

The hydrogen in the coal can be divided into two parts, that present in combination with carbon and that which forms water with the oxygen present in the coal. The generally close agreement between the calorific values calculated by Dulong's formula and those determined directly in the calorimeter would indicate that the oxygen in the coal is largely in such combination as to be equivalent to water as far as heat development is concerned. In considering the composition of coal dried at 105° an amount of the hydrogen equal to $\frac{1}{8}$ of the oxygen present may be assumed as forming with this oxygen the water combined with the organic and mineral matter in the fuel and which will be liberated as water when the fuel is burned. A portion of the sulphur and practically all of the nitrogen may be considered as included in the organic constituents of the coal.

The percentage of oxygen in the analysis is determined by difference, that is, by subtracting the sum of the carbon, hydrogen, nitrogen, sulphur and ash from 100. The result so obtained is in error, being too small by the oxygen absorbed in the ash. If all the sulphur is present as iron pyrites the error would be equal to $\frac{3}{8}$ of the sulphur in the coal, but as only a portion of the sulphur is so present the application of this correction cannot be made when only the total sulphur is known.

Probably the closest approximation to the "organic matter" in the coal is given by the sum of the carbon, hydrogen, oxygen and nitrogen present in the dry fuel. Some sulphur would be included in the organic matter, but this would be in part balanced by any water in the mineral matter expelled in burning to ash, thus causing the oxygen to be estimated too high.

(3rd) Mineral Impurities. The ash in the coal left on burning, as explained above, is not equal in amount to the mineral matter in the coal for the reason that many of the mineral substances present in the coal are altered in the process of combustion.

Coal ash contains silica, alumina, oxides of iron with frequently small amounts of potash, lime and magnesia, the amount of potash sometimes amounting to as much as 2½ or 3%. The source of oxide of iron in the ash is in part at least the combustion of the pyrites, the oxide so derived frequently gives a reddish color to the ash. The silica and alumina are largely derived from clay and sand intimately mixed with the coal in the process of formation or scattered through it as partings or seams of slate. As clay always contains a considerable percentage of water, which is not expelled except at a comparatively high temperature, it is obvious as before stated that in a coal containing considerable ash, especially if high in alumina, there is liable to be noticeable percentage of oxygen and hydrogen present in the ultimate analysis of the dry coal derived from this source and not from the organic matter in the fuel.

A matter of more practical moment in considering the ash in any sample of coal is the distribution of the ash in the seam. Some coals contain considerable percentages of slate, which brings up the ash to a rather high figure, if the sample represents the average of the seam, but if the coal is carefully selected, so as to include none of these slate formations, a low figure for ash would be obtained in the analysis. In coals of this character the screened lumps would show a much lower ash content than the run of mine. In other cases the ash is disseminated through the whole coal and is practically uniform in various parts of the seam and cannot be separated from the coal. Bone coals are of this character, showing a high ash content throughout. This distinction in the distribution of the ash is of prime importance in considering the adaptability of the coals to improvement by washing, as will be discussed later in this chapter.

One of the most important of the impurities of coal is sulphur. The percentage of sulphur in coal is frequently very large. It occurs in coal in at least three ways: The most prominent is in iron pyrites. This mineral is easily recognized in many samples and sometimes forms large masses scattered through portions of the seam, in other samples it occurs as thin plates, in others as very fine grains scattered through the coal in particles too small to be separately recognized. In some of the coals in Ohio, the principal source of sulphur is due to the presence of iron pyrites. A second source of sulphur is the presence of sulphates of iron alumina or lime. It is probable that little or none of these exist in coals that have not had access to recent atmospheric influence, as on exposure to air, some forms of pyrites rapidly absorb oxygen, becoming converted to sulphates, while on the other hand sulphates out of contact with air

are reduced back to sulphides by organic matter. In coals that have been long exposed either in the laboratory or to the weather considerable percentages of such sulphates are frequently found. An important form of sulphur in coal is what is usually designated as "organic sulphur" or sulphur in forms of combination other than the foregoing. But little is known of the actual substances in which the sulphur combines, some coals showing considerable percentages of sulphur even where little pyrites can be recognized or the presence of any appreciable amount of sulphates detected. A little of the sulphur not accounted for as sulphides or sulphates is found as free sulphur in some samples but it mostly appears to be in organic combinations.

The carbon, hydrogen, nitrogen, and oxygen in the ultimate analysis stand for definite substances in the coal. They are reported on the sample as received in the laboratory and include the hydrogen and oxygen present in the moisture in the fuel. In addition to the ultimate analysis the "volatile combustible matter" and the "fixed carbon" are given and the determination of the moisture expelled on heating to 105°.

As has been previously explained, the moisture merely represents that which is expelled from the coal when dried under given conditions and by no means represents all the water which would be given off when the coal is completely burned. The volatile combustible matter and the fixed carbon represent what is usually called the "proximate analysis" of the coal, the "fixed carbon" is the combustible material left in the coke or residue after the coal has been heated to a high temperature in a prescribed manner and for a definite time, and approximately represents what combustible would be left in the coke when the coal is coked. It does not represent all the carbon in the coal, as is clearly seen in comparing the figures for the "fixed carbon" with those given for carbon in the ultimate analysis of the same fuel. The volatile combustible matter represents the volatile material driven off by a high temperature out of contact with air and includes the water formed in the decomposition of the coal by heat, but not that present in the coal as "moisture" at 105°C.

The relation of the fixed carbon to the total carbon varies in different seams and very considerably in different samples from the same seam, though there is a general correspondence in this ratio in coals of the same seam. It should be clearly understood that the fixed carbon is not a definite ingredient of the coal but merely the result obtained by a special method of treatment of the coal, differing in this way radically from the carbon of the ultimate analysis.

A matter of considerable interest is the relation of the sulphur in the coal to the sulphur obtained in the coke. This relation varies greatly in different coals and no general rule can be made for it. A number of determinations will be given later of the percentage of the total sulphur retained by the coke in several samples of Pittsburg coal.

THE HEATING VALUE OF COAL.

The calorific value of a coal is the total amount of heat developed by its complete combustion. It is expressed in the tables in calories, the calorie being the amount of heat required to raise the temperature of one kilogram of water one degree Centigrade. The heating value of coal is frequently expressed in British thermal units, a British thermal unit being the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit. Calorific values given in calories can be converted into calorific values expressed in British thermal units by multiplying the value in calories by 1.8.

The heat of combustion of coal is due to the oxidation of the carbon, the hydrogen not combined with oxygen, the sulphur and the iron not already in combination with oxygen, but the amount of heat produced by the combustion of these elements in combination is not always exactly the same as would be produced by the combustion of the free elements separately. The difference is not so great but that the heat can be calculated from the amounts of the elements present with a fair degree of accuracy.

This is done by what is known as Dulong's formula: $8080C+34460(H-\frac{1}{8}O)+2250\ S$, in which C, H, O and S stand for the amounts of carbon, hydrogen, oxygen and sulphur respectively in the coal. On comparing the average of the different seams it will be seen that the values by Dulong's formula range from 32 calories to 106 calories below those determined by the calormeter. It is not probable that this variation is altogether due to the uncertainty of the determinations, especially the oxygen, but corresponds to actual differences in the heat developed by the different elements when burned in the combinations in which they exist in the coal. Individual variations greater than those indicated in the average occasionally occur while in several samples the results obtained by the direct measurement correspond almost exactly to those calculated by Dulong's formula, and in some cases the results from Dulong's formula are higher than those obtained by direct measurement, though the general tendency is for them to be lower. With very few exceptions the results obtained by Dulong's formula lie within 1½% of the correct calorific value, so that within this limit the formula is useful.

If it be assumed that the calorific value of the coal is due to the combustion of the organic matter and the sulphur, it would seem probable that in coals of like character the calorific value would be proportional to the amount of these substances present. If the percentage of the ash, the moisture and the sulphur be subtracted from 100, the remainder would be approximately the organic matter in the coal and if the calorific value of the sulphur be subtracted from the calorific value of the coal as determined, the remainder should be the calorific value of the organic

matter present. Calculating this to unity gives the value designated as "H" in the table.

In other words, "H"=calorific value minus 2250 times the sulphur, and divided by 1 minus the sum of the ash ,the moisture and the sulphur, the ash, moisture and sulphur being that present in the unit weight of coal. This value for "H" is given for the average of each of the coal seams tested. By reversing this process, the calorific value of each sample has been re-calculated from its ash, moisture and sulphur content by multiplying the value of "H" by one minus the sum of the sulphur, ash and moisture and adding the sulphur multiplied by 2250.

It will be seen by comparison of results that in the great majority of cases the calculated values correspond within $1\frac{1}{2}\%$ of the determined values. Occasionally very considerable variations occur. This would indicate that the assumption that the value of "H" or the calorific value of the organic matter was the same for the whole of an extensive seam was not wholly justified. However, an investigation of the largest variation which occurs in the No. 6 coal in sample 112, where the value calculated from "H" exceeds the value determined in the calorimeter by 8.8%, shows that the sample was taken from the entry about 200 feet from the mouth in a mine, where it had probably been exposed for a long time to the weather. This with its very large percentage of water would seem to indicate that the sample had suffered much alteration from its original condition in the seam.

By comparing the results obtained from "H" in smaller groups of samples covering a limited locality and where the samples were obtained from fresh coal, the agreement between the calculated and determined values is usually close, indicating that in limited portions of a seam and from neighboring mines, the calorific values obtained in the table may be applied with close approximation to the truth to calculate by this method the calorific values of other samples of which the ash, moisture and sulphur are known. This is particularly true for samples representing various shipments of coal from a single mine where the calorific value will vary very closely with the organic matter and sulphur used according to the formula. On the other hand, weathering of the coal by changing the condition of the sulphur and increasing the amount of water in combination with sulphates will rapidly reduce the actual value of the coal as compared with what it should be by the formula, which should never be applied to anything but fresh samples of coal taken from unaltered portions of the seam.

THE AVAILABLE HEAT OF COAL.

The calorific value of coal represents the total heat developed by its combustion. Only a portion of this value can be actually utilized in any practical application of the fuel. A certain amount of it is necessarily

wasted in heating the products of combustion of the fuel and in other ways incident to imperfections of furnaces, etc. The amount of useful heat which a given coal can furnish under given conditions can be approximately estimated from its ultimate analysis and its calorific value.

This may be called the "Available Calorific Power" of the coal and would represent the remainder after subtracting the heat necessarily wasted in the operation. This wasted heat is made up of three main items: (1st) The heat required to raise the products of combustion including the nitrogen in the air necessary to burn the fuel to the temperature at which they escape through the chimney. (2nd) The heat required to evaporate and carry off the moisture in the coal as well as the water formed by the combustion of the hydrogen in the coal; and, lastly, the heat required to raise to the temperature of the chimney the air passing through the furnace in excess of that actually required to burn the fuel. Of course, in actual experience other losses than these will be encountered, losses due to the incomplete combustion of the volatile portions, losses due to radiation, losses due to unburned coal escaping through grates, losses due to heat absorbed by the moisture in the air, etc., but these losses are to a certain extent mechanical and depend on the care used in firing.

The first set of losses are, however, connected intimately with the composition and character of the fuel and cannot be reduced below a certain amount. Different coals will differ in the percentage of their calorific value that is available. The percentage available diminishes with the amount of water and oxygen in the coal and increases with the amount of carbon. If it be assumed that an air excess of 50 per cent. is necessary for the complete combustion of the coal under ordinary conditions, the theoretical available calorific value of a coal could be determined by the following calculations in which H. O. C. S; N, and ash represent the respective amounts of these elements present in the coal; small t and large T the temperature of the air (and fuel) before combustion and the temperature of the escaping flue gases respectively.

The "Available Calorific Power" equals the total calorific value diminished by first, the latent heat, second, the product of the excess temperature of the products escaping and the water equivalent of the products of combustion including the nitrogen in the air consumed; and, third, the product of the excess temperature of the products escaping into the water equivalent of the excess air present.

The value of these deductions is obtained as follows:

First, The latent heat. This equals nine times the hydrogen multiplied by (536.5+.52 (100—t). The item .52 (100—t) being the correction for the difference between the specific heat of water and the specific heat of water vapor.

Second, The products of complete combustion are carbon dioxide, water vapor, sulphur dioxide, nitrogen and ash. The amounts of these

obtained from the unit weight of coal will be $\frac{11}{3}$ of the carbon for the carbon dioxide; nine times the hydrogen for the water vapor; two times the sulphur for the sulphur dioxide and the ash and nitrogen as shown by the analysis. The water equivalent of the products of combustion is obtained by multiplying each of these items by its specific heat and adding the products.

The nitrogen in the air used for combustion is equal to nearly 3.33 times the oxygen required from air for combustion. This oxygen is equal to $\frac{8}{3}$ of the carbon plus eight times the hydrogen plus the sulphur, minus the oxygen contained in the coal. The nitrogen thus calculated multiplied by the specific heat of nitrogen gives the water equivalent of the nitrogen from the air. Similarly, the amount of ash multiplied by its specific heat gives the water equivalent of this item: The sum of all the water equivalents obtained as above multiplied by the difference between the temperatures at which the products escape and the temperature of the air supplied for combustion gives the heat carried off in the products of combustion according to the second item in the general expression

Third. The excess air present is equal to the amount of air required for combustion multiplied by the ratio of the excess air to that required. The air required for combustion is 4.33 times the oxygen required for combustion or 4.33 times the sum of $\frac{8}{3}$ of the carbon plus eight times the hydrogen plus the sulphur minus the oxygen in the coal. The ratio of the excess air present to that used for combustion can be obtained from the analysis of the gases passing out of the chimney. If the small amount of nitrogen present in a coal be neglected the ratio of the air present in the chimney gases to the air used in combustion is equal to

$$\frac{\text{oxygen}}{\frac{3}{10}\text{ of the nitrogen}-\text{oxygen}},$$

in which the oxygen and nitrogen are percentages by weight of the gases. Where the percentages are given by volume the formula becomes

$$\frac{\text{the oxygen}}{\frac{20.8}{79.2}\text{ nitrogen}-\text{the oxygen}}$$

If the fuel contains nitrogen in considerable quantity, which is the case with gaseous fuels, the formula will have to be modified. If V^1 be the volume of gaseous carbon in 100 volumes of flue gas and V the volume of gaseous carbon in 100 volumes of the fuel, considered as a gas, the percentage volume of the nitrogen from the fuel in the flue gas will equal $\frac{V^1 E}{V}$ where E is the percentage by volume of nitrogen in the fuel and the formula for the ratio of air excess will be

$$\frac{O}{\frac{20.8}{79.2}\left(N-\frac{V^1 E}{V}\right)-O}$$

The volume of gaseous carbon is, of course, equal to $\frac{1}{2}$ CO_2 plus $\frac{1}{2}$ CO plus $\frac{1}{2}$ CH_4 in the gas, or generally, the volume percentage of any gas, divided by twice the number of carbon atoms it contains.

The exactness of the above formula for the available heat depends upon the values for the specific heats. The specific heat of nitrogen is usually taken at 0.24 and probably does not change materially at very high temperatures. The specific heat of air is usually taken at 0.237 and probably does not vary to important amounts as the temperature increases. The specific heat of carbon dioxide for ranges of temperature between zero and 350 C is usually taken at .22, but as the temperature increases above this range it rapidly increases and for ranges up to 1,000 degrees will average between .29 and .3 according to the figures quoted by Ackerman. The mean specific heat of water vapor from temperatures of one degree up to 350 degrees will average about .48, increasing as the range increases and by the same authority at 1000 degrees it becomes practically .68. The specific heats of sulphur dioxide and ash up to ranges of 350 are about .15 for the former and .16 for the latter. The foregoing values enable the formula for the available heat to be applied to ordinary conditions of boiler practice with a considerable degree of accuracy.

As an illustration, the available calorific value of the No. 6 coal as based on the average analysis of the seam and under conditions corresponding to the use of the coal in a steam boiler of the best type working under the best conditions is calculated as follows: The excess of air under the conditions assumed is taken at 50%, flue temperature at 300° and the temperature of the air at zero, the temperature at which the ash is withdrawn from the furnace the same as the temperature of the air. The composition and the calorific value are:

Carbon	.6903
Hydrogen	.0543
Nitrogen	.0126
Oxygen	.1362
Sulphur	.0330
Ash	.0706
Calorific value	6,980 calories.

The latent heat equals $9 \times .0543 \times (536.5 + .52\ (100) = 287.5$.

The water equivalent of the products of combustion exclusive of the nitrogen in the air equals:

$$
\begin{array}{lll}
.6903 \times \frac{11}{3} & \times .22 & = 0.5568 \\
.0543 \times 9 & \times .48 & = 0.2345 \\
.0330 \times 2 & \times .15 & = 0.0990 \\
.0126 \times 0.24 & & = 0.0032 \\
\hline
 & & \ 0.8935
\end{array}
$$

The oxygen in the air used in combustion equals:

$\frac{8}{3}$ x .6903	= 1.8408
8 x .0543	= .4344
Sulphur	= .0330
	2.3082
Deducting the oxygen in the fuel	.1362
	2.1720

The water equivalent of the nitrogen in the air corresponding to the oxygen equals $3.33 \times .24 \times 2.1720 = 1.7359$.

The water equivalent of the products of combustion plus the nitrogen from the air equals the sum of these two water equivalents, which is 2.6294 which multiplied by 300°, the flue temperature, equals 788.8, the sensible heat carried off in the products of combustion.

The excess air equals the oxygen (2.1720) multiplied by 4.33 and by .5, (the ratio of air excess) giving 4.7024. The heat carried off in excess air equals:

4.7024 x .237 x 300° = 334.3 heat units.

Writing these various values together and adding them, we have as follows:

287.5	Latent heat.
788.8	Heat lost in products of combustion including N. from air used.
334.3	Heat lost in excess air in flue gas.
1,410.6	Total.

Deducting the sum—1410.6—from the calorific value of the fuel—6980—leaves 5569.4, as the heat theoretically available per unit of fuel and under the conditions assumed. This is equal to about 80% of the total calorific value.

The evaporating power of a coal as used in boilers is more or less closely connected with the available heating power, but, of course, is greatly modified by the adaptability of the coal to burning on the particular grate and in the particular furnace used. Certain other losses occur under the best construction and can only be partially avoided even in the best practice. If the sum of these other losses be deducted from the available heating power, the practical evaporating power per pound of coal in pounds of water at the boiling point turned into steam at the same temperature, would be the remainder divided by 536½. Coals differ in the percentage of the excess of air required for their complete combustion and it is well known that experience with the kind of coal is necessary to use it to the best advantage.

A large number of experiments on the boilers of the United States Government Fuel Testing Plant at St. Louis have shown an average loss

of approximately 10 per cent. of the calorific value of the coal in undetermined losses connected with radiation, incomplete combustion, etc. If it be assumed that this figure represents first class practice, the evaporating power which should be obtained from a coal under the best conditions in use would be approximately the available calorific power as estimated before, less 10% of the calorific value and divided by 536.5. As an example, if 10% of the calorific value be deducted from the available calorific power of the above coal there is left 5568.7—698.=4870.7 and this divided by 536.7=9.07 as the number of pounds of water 1 lb. of this coal should evaporate under the best boiler conditions.

As it is rarely possible to completely burn the coal, five per cent. may be assumed for loss through the grates, in smoke and other modes of incomplete combustion, which would reduce the figure to 9.07—.45=8.62 as the best practical evaporative power of the average of the No. 6 coal in boilers not provided with special means of saving the chimney losses.

Larger air excess or higher flue temperature will of course increase the losses proportionately.

Thus 100% excess of air, a figure more usually found, would double the loss due to this cause and reduce the available heat by a further 334.5 units or reduce the evaporation by 334.5 divided by 536.5=.62 or to 8.00 lbs. from and at the boiling point.

It is not to be understood that these figures are generally realized with the coal but represent the actual possibilities of the coal which is certainly capable of giving these results.

The relative commercial value of coals as indicated by their analysis and calorific value may be considered under two aspects: In the first place, as to the actual heating value of the combustible portion of the coal and the percentage of this heating value available. In a general way the calorific values of fuels are an indication of their relative fuel value, but from what has preceded it is evident that a closer comparison of the relative values of coals for any particular purpose will be afforded by a comparison of their available calorific power under the conditions as to temperature and combustion under which they are to be used.

Coals which contain or furnish on burning large percentages of water will give low percentages of available heat calculated on their total calorific power both from the latent heat and the large quantity of heat carried off in the water vapor in the products of combustion. The effect of this latter item will be increasingly seen, as the temperature at which the gases escape is increased. An important result is also to diminish the possible furnace temperature obtainable where coals producing large quantities of water vapor are used. Inspection of the analytical tables given later on in this report shows that the Ohio coals differ but little in different seams in their hydrogen and oxygen percentages, so that this cause of difference is not particularly important in com-

paring the coals of this state, but becomes important if they are to be compared with other fuels differing widely in moisture and oxygen percentages. It is obvious that the moisture determination is one of importance and always to be considered in connection with the total calorific value of the coal.

In the second place the effect of the impurities, moisture, ash and sulphur, on the value must be considered. These affect the available heat produced by the coal. The ash by replacing the combustible matter acts directly in reducing the total calorific power of the coal and of course proportionately the available calorific power of the coal. A coal with 15% of ash will have 5% less combustible matter than one with 10% of ash, so that from this point of view alone the relative values of the two coals would be approximately as 85 to 90. The sulphur in a coal has a heating value of its own and when in the form of pyrites produces probably in the neighborhood of one half as much heat by its combustion and that of the iron combined with it, as would the organic matter that it replaces.

The moisture in the coal as has already been indicated, not only reduces the heating value by the organic matter it replaces but diminishes by a considerable amount the availability of the heat produced by combustion. Five per cent. of water under the conditions of ordinary boiler practice would not only reduce the heating power by five per cent., but would increase the latent heat by about thirty calories. The excess of loss produced by moisture will partly offset the heat produced by the combustion of the sulphur, so that the relative values of the coals having the same value for the combustible would be approximately proportionate to one minus the ash, the moisture and the sulphur. In other words, coal in a given seam with five per cent. of moisture, ten per cent. ash and two per cent. of sulphur as compared with a coal with eight per cent. of moisture, twelve per cent. of ash and four per cent. of sulphur would rank as about 1—17 to 1—24 or as 83 to 76, or on a percentage basis, one ton of the purer coal would be equivalent to nearly 1.1 of the more impure.

Many other considerations, however, besides the actual heating value enter into the relative value of coal. Excess of ash of course involves extra expense in handling. Excess of sulphur for many purposes is injurious to the process to which the coal is applied. No general rule can be given for these items, as they depend upon the application of the coal and other special conditions.

The tendency of coal to smoke and form soot varies greatly but the loss of heat due to the formation of soot is very small and the effect on the value of coal for heating purposes but slight, though for many other reasons it may be a large factor in determining the relative values of coal for special purposes. The character of the ash distinct from its amount is a factor not represented in the analysis, but of importance, badly

clinkering or fusing ash being highly objectionable in coals used for certain purposes.

ANALYTICAL RESULTS.

The tables which follow in this chapter give the analytical results and calorimetric determinations on the samples tested. The samples are grouped according to the geological classification of the coal seam. The samples in each group are arranged approximately according to their geographical location proceeding from the southern to the northern portion of the state.

The table headed "Moisture"' gives the moisture in the coal as present in the sample as received in the laboratory. All the other determinations are upon the coal containing this moisture and not upon the dried sample. The oxygen as given in the tables is determined by difference.

The Clarion or No. 4 Coal.

The samples of this coal cover a territory forming a narrow strip running a little east of north from the junction of Scioto and Lawrence Counties to the middle of the eastern part of Vinton County. The coal in all cases is high in sulphur, in some samples running over six per cent. Inspection of the location of the samples shows a general tendency for the sulphur to run highest in the more easterly samples from the general direction of the line: However, there is apparently no definite law for the distribution of the sulphur or the ash, considerable variations occurring in samples from the same township. From the average analysis of all the samples the composition of the dry organic matter can be calculated on the assumption that it is equal to the sum of the carbon, hydrogen, nitrogen and oxygen in the dry coal, as follows: From the sum of the carbon, hydrogen, nitrogen and oxygen in the moist coal as given deduct the moisture. Divide the carbon, the hydrogen minus $\frac{1}{9}$ the moisture, the nitrogen and the oxygen minus $\frac{8}{9}$ the moisture by the remainder, and the quotients each multipled by 100 will give the percentage of carbon, hydrogen, nitrogen and oxygen in the dry organic matter in the coal.

In order to test the variations in different samples the average of the two highest sulphur coals in the No. 4 seam and the average of the two lowest sulphur coals were also calculated. The results were as follows:

Composition of the Dry Organic Matter of No. 4 Coal.

	Average of whole seam.	Average of Nos. 62 and 63, two highest sulphurs.	Average of Nos. 54 and 70, two lowest sulphurs.
Carbon	81.73	82.90	81.90
Hydrogen	5.93	5.87	5.92
Nitrogen	1.57	1.73	1.54
Oxygen	10.77	9.50	10.64
	100.00	100.00	100.00
Sulphur	4.33	6.11	3.09

It will be seen that there is considerable variation in the oxygen and in the carbon in the two sets of results as calculated. A further calculation was made to compare them in the same way after correcting the oxygen by adding an amount equal to $\frac{3}{8}$ of the sulphur and then reducing to the percentage basis by dividing each of the items of the analysis of the dry organic matter by their sum with the oxygen so increased. The results are given for the three averages as follows:

Composition of the Dry Organic Matter in No. 4 Coal after correction for sulphur.

	Average whole seam.	Two highest sulphurs.	Two lowest sulphurs.
Carbon	80.05	80.44	80.80
Hydrogen	5.81	5.64	5.84
Nitrogen	1.54	1.72	1.50
Oxygen	12.60	12.20	11.86
	100.00	100.00	100.00

It will be seen that in this case the results are more nearly alike, from which it is a fair inference that the sulphur in the No. 4 coal is largely present as pyrites and that the ultimate analysis on this latter supposition is a nearer approximation to the composition of the dry organic matter than that obtained by the first method. If the composition of the organic matter of the seam be taken as that given by the results on the average of the seam, the ultimate analysis of any particular sample of the No. 4 coal could be obtained with a fair degree of accuracy from

the determination of the ash, moisture and sulphur for the particular sample.

The method of calculation would be to simply reverse that by which the foregoing results were obtained. In other words, subtract from unity the ash, the moisture and $\frac{5}{8}$ of the sulphur present in a unit weight of coal and multiply the items in the analysis of the organic matter corrected for sulphur by the result. This will give the carbon, hydrogen, nitrogen and oxygen for the particular sample, the oxygen being corrected for sulphur. By subtracting $\frac{3}{8}$ of the sulphur from the oxygen the result will be the oxygen as given in the ordinary analysis, where it is determined by difference. To include the hydrogen and oxygen present in the moisture in the coal, add $\frac{1}{9}$ of the moisture to the hydrogen and $\frac{8}{9}$ to the oxygen. The sum of the results plus the ash and the sulphur should equal 100%, as a check on the calculation. Of course, this method would not be satisfactory if applied to altered or weathered samples of coal, which have changed radically from the composition of the seam in its normal condition.

The average heating value of the No. 4 coal is 6637 calories, equivalent to 11947 B. T. U. The heating value of "H," as explained previously for the seam is 8223 caloris. The heating values for the different samples tested calculated from this average value for "H" are given in the table. In the majority of cases, the correspondence is fairly satisfactory, showing in a general way that the heating value of the coal after making due allowance for the variations in ash and moisture is approximately constant. It will be noted that the heating value in any sample by Dulong's formula does not differ by more than one per cent. from that determined by the calorimeter. It will be noted that there are wide variations in the percentage of ash, moisture and sulphur in the different samples of coal, indicating considerable difference in the cleanness of the coal from different points and the necessity of careful determination of these constituents in comparing the value of coals from different shipments.

The Lower Kittanning or No. 5 Coal.

The samples of No. 5 coal were taken at widely separated points over the state extending from the Ohio River on the south to Mahoning County on the north. Considerable variations in the quality of the coal are shown, the sulphur varying from 2.13 to 4.80 and the ash from 4.72 to 10.16. The average composition of the dry organic matter in the samples examined is as follows:

	Corrected for sulphur.	Not corrected for sulphur.
Carbon	81.86	83.06
Hydrogen	5.64	5.74
Nitrogen	1.50	1.52
Oxygen	11.00	9.68
	100.00	100.00
Sulphur	.....	3.26

The average calorific value of the coal as determined is considerably higher than the calorific value as calculated by Dulong's formula, and this relation exists through all the samples examined with one exception in which the two are practically identical. The value of "H" as determined for the seam or the heating value of the coal free from ash, sulphur and moisture as determined from the average of all the analyses is 8363 calories.

It will be noted that in the calorific value of the individual samples recalculated from the value of "H" considerable variations occur amounting in one case to 3.8 per cent., from the values determined in the calorimeter. It appears that in the samples in the southern part of the state the heating values calculated from the average all run lower than those actually determined while in the northern portion of the state they run higher.

In so far as a conclusion would be warranted from the limited number of samples analyzed, this would indicate that the heating value of the actual coal was higher in the southern portion than in the northern portion of the state. The number of samples of this coal taken was not sufficient to indicate with certainty local variations in the field and the ultimate analysis and calorific value of any particular sample would only be applicable to the neighborhood of the location of the sample taken.

The Middle Kittanning or No. 6 Coal.

The samples of No. 6 coal cover a territory extending from Lawrence County near Ironton in a direction slightly east of north up to Coshocton, from thence in a more easterly direction nearly to Alliance on the border of Columbiana County. The first important group is principally located in the eastern part of Hocking, the western part of Athens, the whole of Perry and through Muskingum County. The second important group of samples covers Coshocton and Tuscarawas Counties. Scattered samples only, represent the rest of the field.

The average composition of the dry organic matter is as follows:

	Corrected for sulphur.	Not corrected for sulphur.
Carbon	81.68	82.88
Hydrogen	5.68	5.77
Nitrogen	1.50	1.51
Oxygen	11.14	9.84
	100.00	100.00
Sulphur	.....	3.30

In order to investigate which of these two statements applies best to the No. 6 coal, the determination of the composition of the dry organic matter of four coals among those highest in sulphur, Nos. 101, 133, 114, and 117 in the tables of analyses, were compared in the same way with four of the low sulphur samples, Nos. 89a, 83, 90, and 86. The results are as follows:

Not Corrected for Sulphur.

	Average 4 high sulphur.	Average 4 low sulphur.
Carbon	82.98	81.60
Hydrogen	5.98	5.51
Nitrogen	1.48	1.60
Oxygen	9.56	11.29
	100.00	100.00

Corrected for Sulphur.

	Average 4 high sulphur.	Average 4 low sulphur.
Carbon	81.02	81.36
Hydrogen	5.83	5.49
Nitrogen	1.45	1.55
Oxygen	11.70	11.60
	100.00	100.00

It will be seen from these examples that the composition of the organic matter after the correction for sulphur is practically identical in these coals, which would justify the conclusion that most of the sulphur in the No. 6 coal was present in the form of iron pyrites and that the ultimate analysis of the two sets of samples was quite constant if based on the dry organic matter. The value of "H" or the heating value of the combustible in the seam is 8243. The calorific value for the average of the seam as determined by Dulong's formula is 45 calories below the average of the determinations in the calorimeter, equivalent to six-tenths of one per cent. It will be noted that in the great majority of cases the results by Dulong's formula correspond quite closely to the determination in the calorimeter.

The calorific values of the individual samples derived from the value of "H" for the seam, with a few exceptions, agree fairly closely with the determinations made in the calorimeter. There are several wide variations, however. To one of these attention has been called before. The next largest variation is in sample No. 119. The field notes show that all the coal in this mine is more or less red or weathered, though the sample cut was as yet black on the butts. The coal is soft and cuts easily and crumbles. There is but one bench. Sample 137, which also falls widely out of line, is in Columbiana County and far removed from the rest of the field and seems to indicate as far as a single sample can, that the coal had changed markedly in character at that point. With these exceptions the value of "H" agrees fairly well in the different samples.

The samples of No. 6 coal vary in sulphur all the way from 5.60 down to .51. A study of the location of the samples together with the determination of sulphur indicates that the percentage of sulphur in the coal varies somewhat regularly with the geographical location of the samples, the few samples taken in Lawrence and Gallia Counties running between three and four per cent. in sulphur. Passing north to the Hocking field, the samples from the adjoining townships, Ward in Hocking County, Blacklick and Monroe in Perry County and Trimble in Athens all show less than 1½ per cent. and in most cases less than one per cent. of sulphur, indicating a large area of low sulphur coal.

South and west of this area of low sulphur, the sulphur contents increases ranging from 1½% to 3% in the northern part of Athens County, the eastern part of Hocking and the central part of Perry County. Going to the north the sulphur in the samples increases rapidly reaching a high sulphur area in the southern part of Muskingum County, in which the samples run from four to five per cent. and over. The sulphur is high, in the rest of the field only passing below 3 per cent. in one sample occurring in Coshocton County, becoming very high again in the northeastern part of Coshocton County, where it again reaches a maximum of over five per cent. From this point north the sulphur again drops until in the northern part of Tuscarawas and southern part

of Stark the samples run under three per cent. These results indicate clearly that the distribution of the sulphur in the No. 6 coal is not erratic but passes with more or less regularity from well defined points of low sulphur in the seam to points of maximum sulphur.

If the heating value of the individual samples calculated from "H" be compared with the actual calorimeter determination in these different districts, it will be noticed that in the Hocking valley region of low sulphur, the values calculated from "H" are uniformly above those determined from the calorimeter, agreeing rather closely in the amount. This shows that the low sulphur coals in this district had lower heating values for the actual combustible than some of the high sulphur coals in the more northern part of the state.

The following table gives the average composition of the six low sulphur Hocking Valley samples, Nos. 86, 87, 88, 90, 79 and 91, two of the Muskingum County samples, 101 and 96, three of the high sulphur group in Coshocton County, 114, 117 and 133, and in the low sulphur group 138, 126 and 135.

	First low sulphur group, Hocking field.	Muskingum Co., High sulphur.	Coshocton Co. High sulphur.	Second or northern low sulphur.
Moisture	7.37	5.05	4.24	6.24
Ash	5.96	9.66	9.24	6.61
Sulphur	0.97	5.76	5.39	2.73
Carbon	69.96	65.81	67.44	70.23
Hydrogen	5.50	5.30	5.31	5.47
Nitrogen	1.33	1.13	1.21	1.24
Oxygen	16.28	12.34	11.42	13.73
Calories determined	6947	6780	6869	7084
Calories from "H"	7086	6685	6808	7020
Value of "H"	8080	8360	8320	8320

The value of "H" is calculated for each group from the average of the group.

The value of "H" given here should be used in estimating the heating value of samples of the Hocking Valley coals and will give more correct results than using the value of "H" for the whole seam. The increase in the heating value of the coals that are high in sulphur may be due either to the fact that too low a rating is given to the combustion of sulphur through making no allowance for iron burned at the same time or to an actual higher heating value of the combustible material of the coal in these coals. The composition of the dry organic matter in these portions of the No. 6 seam calculated from the foregoing averages is given in the following table both corrected for sulphur and not corrected for sulphur.

Composition of the dry combustible.

Not Corrected for Sulphur.

	6 Hocking Valley samples.	Muskingum Co. samples.	High Sulphur group, Coshocton Co.	Northern low sulphur group.
Carbon	81.64	82.76	83.14	83.20
Hydrogen	5.46	5.96	5.96	5.67
Nitrogen	1.55	1.41	1.47	1.46
Oxygen	11.35	9.87	9.43	9.67
	100.00	100.00	100.00	100.00
Sulphur	0.97	5.76	5.39	2.73
Corrected for Sulphur.				
Carbon	81.34	80.58	81.14	82.22
Hydrogen	5.44	5.80	5.83	5.62
Nitrogen	1.49	1.37	1.39	1.41
Oxygen	11.73	12.25	11.64	10.75
	100.00	100.00	100.00	100.00

These figures show that the northern group after correcting for sulphur was noticeably lower in oxygen and higher in carbon than the Hocking Valley coals, indicating a distinct change in the character of the coal from the southern to the northern part of the seam and corresponding to the indication in the calorimeter. It is interesting to notice a similar change in the percentage of moisture found in these coals, this being noticeably higher in the southern part of the state than in the northern, as would be expected from the higher oxygen contents of the coal and decrease in carbon.

The analysis of the No. 6 coal would seem to warrant the conclusion that the changes in the quality of the coal are not erratic or abrupt but progressive and that the analysis of the tables could be applied with considerable confidence to determine the character of the coals in the vicinities of the points sampled.

The fixed carbon in the No. 6 coal averages 48.96%. The average ratio of volatile matter to fixed carbon is 1.29 as compared with 1.31 for the No. 5 coal and 1.15 for the Clarion coal. The variation of this ratio for different samples of the same coal is very considerable. Taking the average of the six samples of the Hocking Valley coal given above, the ratio of volatile matter to fixed carbon is 1.54; for the three Coshocton County samples the ratio of volatile matter to fixed carbon is 1.18. In the latter group the calorific values determined from "H" are all considerably below the calorimeter results, which in the Hocking valley group

they are all considerably above, showing that the low ratio of fixed carbon to volatile matter in the Coshocton County coals goes with a marked increase in the value of the heating power of the organic material of the coal. This ratio, the so-called "fuel ratio," first proposed years ago by Dr. Ashburner, would appear to be no indication of the relative heating value of the combustible material in this seam.

The Upper Freeport or No. 7 Coal.

The samples representing the No. 7 coal form two groups: (1) being the Waterloo coal in the northern part of Lawrence and southwestern part of Gallia Counties; (2) the northern No. 7 in which most of the samples are located in Muskingum covering a small area east of Zanesville. One sample was taken in Coshocton County nearly due north of the Zanesville group.

The average calorific value of the southern group of samples is 6504 calories, 106 calories higher than calculated by Dulong's formula from the average of the coals. The value of "H" is 8074 calories and the heating value of the individual samples calculated from this value of "H" agrees very closely with the heating value as determined by the calorimeter, showing the general character of the combustible organic matter to be practically uniform throughout the small group composing the Waterloo field. The average composition of the dry organic matter calculated as before is as follows:

	Corrected on the assumption that sulphur is all present as pyrites.	Not corrected for sulphur.
Carbon	80.93	81.52
Hydrogen	5.36	5.40
Nitrogen	1.57	1.58
Oxygen	12.14	11.50
	100.00	100.00
Sulphur	.....	1.62

The ratio of fixed carbon to volatile matter for the southern group is 1.53. It will be noticed that this group of coals agrees very closely in fuel ratio with the Hocking valley group of the No. 6 coal, and it agrees with it quite closely in the composition of the dry organic matter calculated on the sulphur free basis and still more closely when calculated on the analysis not corrected for sulphur.

Corrected for Sulphur.

	Southern Group No. 7.	Hocking Valley Group No. 6.
Carbon	80.93	81.34
Hydrogen	5.36	5.44
Nitrogen	1.57	1.49
Oxygen	12.14	11.73
	100.00	100.00
Sulphur	.....	.....
Not Corrected for Sulphur.		
Carbon	81.52	81.64
Hydrogen	5.40	5.46
Nitrogen	1.58	1.55
Oxygen	11.50	11.35
	100.00	100.00
Sulphur	1.62	0.97

The value of "H" for the samples of the Hocking Valley group of the No. 6 coal is 8080 and for the Waterloo coal 8074.

The northern group of samples of the No. 7 coal are markedly higher in sulphur and lower in moisture, the change in this respect corresponding to the change in the No. 6 coal as it passes to the northern part of the state. In these northern samples the "fuel ratio" also falls to 1.18, following in this respect the large drop in "fuel ratio" in the No. 6 coal in the northern portion of the field. The composition of the dry organic matter in the No. 7 coal in the northern field is as follows:

	Corrected for sulphur.	Not corrected sulphur.
Carbon	80.86	82.25
Hydrogen	5.77	5.87
Nitrogen	1.49	1.50
Oxygen	11.88	10.38
	100.00	100.00
Sulphur	.....	3.80

It will be noticed that after correcting for sulphur the analysis from the two fields are nearly identical, but by correcting for sulphur there is quite a marked difference in the percentages of carbon and oxygen. The average sulphur in the northern samples is more than double that in the southern samples. The value of "H" for the northern samples is 8280, which would apparently correspond to a low oxygen and a higher carbon content. In the northern coals as in the southern the average heating value calculated by Dulong's formula is noticeably lower than the heating value determined in the calorimeter. The agreement in individual samples between the heating value calculated from "H" and the heating value determined in the calorimeter is fairly satisfactory.

The three samples taken in the southern part of Mushingum County are all very high in sulphur as compared with the samples in the southern district. A single sample taken in Coshocton County is lower in sulphur, higher in moisture and approximates more nearly in analytical character to the samples in the southern part of the state, having the high "fuel ratio" shown in that district.

The Pittsburg or No. 8 Coal.

The samples representing this coal cover the southern part of Gallia County, where a small number were taken, part of Athens County, all of Belmont, the southeastern part of Harrison and the southern part of Jefferson Counties. The samples form three general groups representing detached fields of the No. 8 coal. Four samples in Gallia County are high sulphur coals and show more heating value as determined by the calorimeter than is given by calculation from Dulong's formula.

The average value of "H" for all of the samples of the Pittsburg seam is 8363. The heating values of the Gallia County samples calculated from this value all exceed very decidedly the heating values observed in the calorimeter. The small group of samples taken in Athens and Morgan Counties are very close in general analytical character to those taken in Gallia County, being high in sulphur and moisture. The correspondence between the results by Dulong's formula and the results from the calorimeter is fairly close and they agree with the samples from Gallia County in that all the values derived from "H" are noticeably higher than those determined in the calorimeter. These facts would indicate that the No. 8 coal in these localities was distinctly different in analytical character and heating value from the Belmont County district. The composition of the dry organic matter in the coal calculated from the average of the whole seam is as follows:

	Corrected for sulphur.	Not corrected for sulphur.
Carbon	82.31	83.73
Hydrogen	5.58	5.68
Nitrogen	1.36	1.37
Oxygen	10.75	9.22
	100.00	100.00
Sulphur	.....	3.81

The sulphur in the samples from the southern and western portions of Belmont County is in all cases over 4%. In the western part of Harrison and south-western part of Jefferson, there appears to be a circumscribed area covering Athens, Short Creek, Mt. Pleasant, Smithfield and Wayne townships, in which the coal is considerably lower in sulphur, most all of the samples containing under 3% and a number of them under 2%. The moisture in the samples from the Belmont district is considerably lower than in the samples from the southern part of the field, as appears to be the case in the other seams of coal extending through the state. The general analytical difference between the samples of the Belmont County district and those from the southern portion of the state in Athens and Gallia Counties is shown by the following table:

	Average South. Athens & Gallia Co. Nos. 25-22 in table.	Average North. Belmont Distt. trict Nos. 9-17 in table.
Moisture	6.39	4.13
Volatile Matter	36.58	36.27
Fixed carbon	47.06	50.78
Ash	9.97	8.81
Sulphur	4.31	3.64
Hydrogen	5.17	5.21
Carbon	65.53	70.15
Nitrogen	1.01	1.17
Oxygen	14.00	11.02
Calories determined	6604	7101
Calories by Dulong's	6571	7069
Calories from "H"	6731	.....
Difference by Dulong's	—0.50	.....
Difference from "H"	+1.92	.....

The composition of the dry organic matter the value of "H" and the "fuel ratio" for the two groups are as follows:

Corrected for Sulphur.

	No. 8 South.	No. 8 North.
Carbon	80.94	82.78
Hydrogen	5.51	5.60
Nitrogen	1.28	1.35
Oxygen	12.27	10.27
	100.00	100.00
Value of "H"	8202	8412
Fuel ratio	1.28	1.40
Not Corrected for Sulphur.		
Carbon	82.58	84.08
Hydrogen	5.62	5.69
Nitrogen	1.31	1.42
Oxygen	10.49	8.81
	100.00	100.00

The Pomeroy or No. 8a Coal.

The samples representing this coal cover a small area in Meigs County and the north-eastern portion of Gallia County around Pomeroy. With one exception the samples are only moderately high in sulphur. The average heating value of the samples calculated by Dulong's formula falls about nine-tenths of a per cent. below the heating value determined in the calorimeter. There is considerable variation among the individual samples, but in most cases the heating value determined is noticeably in excess of the heating value as calculated by the formula. The value of "H" or the heating value of the dry combustible matter is 8156 and in no case does the heating value of the individual sample depart more than one per cent. from the heating value calculated from the value of "H," showing considerable uniformity in the quality of the combustible material. The ultimate analysis of the dry organic matter with the oxygen uncorrected and corrected for sulphur is as follows:

	Corrected for sulphur.	Not corrected for sulphur.
Carbon	80.58	81.50
Hydrogen	5.72	5.78
Nitrogen	1.32	1.32
Oxygen	12.38	11.40
	100.00	100.00
Sulphur	.....	2.42

The fuel ratio or fixed carbon divided by volatile matter is 1.37, but this ratio varies very markedly in the different samples. In sample No. 30, the fuel ratio is 1.55 and in Sample No. 33, it is 1.27. It is noticeable that the one with the low fuel ratio shows a higher heating value in the calorimeter than the results calculated from the average and the one with the high fuel ratio shows a lower result in the calorimeter than when calculated from the average.

The Meigs Creek or No. 9 Coal.

The territory covered by the samples of this coal forms two well defined areas:—the first, occupies the northern part of Washington, the eastern part of Morgan and most of Noble counties, including a more or less circular field. The second group covers Belmont County and the south-eastern part of Harrison County, most of the samples lying in Belmont. The average calorific value of all the samples as determined in the calorimeter is 6800 calories. The calorific value calculated by Dulong's formula is 41 calories lower or six-tenths of a per cent. The value of "H" or the heating value of the combustible figured from the whole seam is 8379 calories. It will be seen that the majority of the samples when recalculated from the general average agree within one and one-half per cent., only one sample exceeding this amount. The ultimate analysis of the dry organic matter uncorrected and corrected for sulphur is as follows:

	Corrected for sulphur.	Not corrected for sulphur.
Carbon	81.77	83.40
Hydrogen	5.68	5.80
Nitrogen	1.23	1.25
Oxygen	11.32	9.55
	100.00	100.00
Sulphur	.....	4.28

Considering the two groups of samples separately the average sulphur of the southern or Morgan and Noble County group is 5.30, for the northern or Belmont County group 2.88 per cent., the samples from the more northern portion of this latter field being very noticeably lower in sulphur. The average analysis of the dry organic matter for the two fields both corrected and uncorrected for sulphur are as follows:

The Southern or Morgan and Noble County Group.

	Corrected for sulphur.	Not corrected for sulphur.
Carbon	81.76	83.38
Hydrogen	5.82	5.94
Nitrogen	1.12	1.14
Oxygen	11.30	9.54
	100.00	100.00
Sulphur	.....	5.30

The Northern or Belmont County Group.

	Corrected for sulphur.	Not corrected for sulphur.
Carbon	82.61	83.50
Hydrogen	5.54	5.60
Nitrogen	1.39	1.40
Oxygen	10.46	9.50
	100.00	100.00
Sulphur	.....	2.88

The southern group is noticeably higher in oxygen and lower in carbon in the analysis after correction for sulphur, though the two groups correspond very closely if the correction for sulphur is omitted. The average moisture of the southern group is distinctly lower than in the northern portion of the field. The fuel ratio of the No. 9 coal for the average of the whole seam is 1.34. This ratio, however, varies widely in the different samples of coal and apparently is not connected in any way with variations in the heating value. The ash contents does not appear to vary in any regular way with the location of the samples.

GENERAL CONCLUSIONS.

The foregoing review of the analytical results which are given in full in the tables that follow would seem to indicate that the moisture, sulphur and heating value of the various seams were tolerably constant in particular portions of the seam, but that they changed somewhat systematically from one general portion of the seam to another. This conclusion is of importance as it warrants the application of the published analyses with reasonable confidence in estimating the quality of the coal in the neighborhood of the location from which the individual samples were taken. Of course, it is not claimed that the law is rigid, but that there is sufficient correspondence to give considerable confidence in the application.

ANALYTIACAL TABLES.

CLARION OR NO. 4 COAL.

Publication No.	County.	Township.	Moisture at 105° C.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific value determined.	Calorific value calculated by Dulong's formula.	Calorific value calculated from "H" = 8223.	Variation of value by Dulong's formula from actual determination.	Variation of value from "H" from actual determination.
															Percent.	Percent.
65	Lawrence	Decatur	6.34	35.30	40.95	17.41	5.29	4.91	57.92	1.07	13.40	5967	5914	5954	—0.90	—0.20
67	"	"	5.86	37.25	41.61	15.28	5.36	5.06	60.22	1.18	12.90	6185	6175	6165	—0.20	—0.30
68	"	"	6.11	38.43	45.52	9.94	3.61	5.42	65.53	1.22	14.28	6643	6631	6687	—0.20	+0.70
66	"	Washington ..	6.00	39.16	42.98	11.86	5.10	5.26	63.32	1.22	13.24	6519	6475	6450	—0.70	—1.10
64	Scioto	Bloom	6.80	37.92	45.94	9.34	3.45	5.33	65.30	1.23	15.35	6535	6528	6690	—0.10	+2.40
63	Jackson	Madison	4.90	35.75	45.65	13.70	6.14	4.89	62.57	1.23	11.47	6386	6386	6327	0	—0.90
62	"	Bloomfield ...	5.31	37.33	43.82	13.54	6.08	4.98	62.05	1.23	12.12	6323	6346	6310	+0.40	—0.20
55	"	Milton	5.61	38.92	47.38	8.09	3.70	5.47	67.30	1.28	14.16	6821	6794	6875	—0.40	+0.80
56	"	"	4.98	39.71	45.51	9.80	4.08	5.39	66.14	1.28	13.31	6752	6720	6764	—0.50	+0.20
57	"	"	4.71	40.51	46.17	8.61	3.73	5.44	67.51	1.26	13.45	6867	6834	6905	—0.50	+0.60
60	"	"	5.33	41.01	45.26	8.40	3.72	5.50	66.52	1.28	14.58	6781	6726	6872	—0.80	+1.30
59	Vinton	Wilkesville ...	4.72	39.88	44.19	11.21	4.16	5.36	65.04	1.28	12.95	6694	6637	6665	—0.90	—0.40
61	"	" ...	4.52	40.10	46.53	8.85	4.23	5.44	67.17	1.28	13.03	6854	6834	6871	—0.30	+0.30
54	"	Vinton	5.02	40.31	46.51	8.15	2.81	5.49	68.52	1.28	13.69	6927	6903	6969	—0.40	+0.69
58	"	"	4.61	41.35	42.94	11.10	5.28	5.36	64.91	1.30	12.05	6696	6694	6616	0	—1.29
70	"	Madison	5.02	39.90	46.11	8.97	3.32	5.48	67.92	1.33	12.98	6960	6895	6875	—0.90	—1.20
69	"	Elk	4.95	39.17	46.56	9.32	3.53	5.40	67.17	1.30	13.28	6914	6797	6838	—1.70	—1.10
	Average	.....	5.34	38.94	44.92	10.80	4.33	5.30	65.01	1.25	13.31	6637	6605	6637	—0.50	0

LOWER KITTANNING OR NO. 5 COAL.

Publication No.	County.	Township.	Moisture at 105° C.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific value determined.	Calorific value calculated by Dulong's formula.	Calorific value calculated from "H" = 8363.	Variation of value by Dulong's formula from actual determination.	Variation of value from "H" from actual determination.
															Percent.	Percent.
74	Lawrence	Perry	7.57	38.51	45.13	8.79	3.20	5.59	66.71	1.27	14.44	6777	6764	6799	—0.20	+0.30
75	"	Elizabeth	8.07	34.54	47.68	9.71	2.13	5.44	65.54	1.23	15.95	6626	6533	6746	—1.40	+1.80
76	Jackson	Milton	8.39	35.18	49.01	7.42	2.65	5.47	66.63	1.37	16.46	6772	6621	6879	—2.20	+1.60
71	Perry	Pike	6.85	35.22	47.77	10.16	4.72	5.26	64.78	1.22	13.86	6591	6557	6652	—0.50	+0.90
72	"	"	6.74	37.05	49.09	7.12	2.58	5.47	68.34	1.24	15.25	6885	6808	7046	—1.10	+2.30
73	Muskingum ...	Washington ..	5.05	39.75	47.43	7.77	4.80	5.37	68.07	1.18	12.81	6983	6908	6997	—1.00	+0.20
77b	Jefferson	Knox	2.46	38.48	51.66	7.40	3.82	5.38	74.20	1.27	7.93	7591	7589	7305	0	—3.80
77	Tuscarawas ...	Sandy	5.30	38.73	48.26	7.71	3.25	5.46	69.75	1.18	12.65	7168	7044	7076	—1.70	—1.30
77a	Mahoning	Green	5.23	36.86	53.19	4.72	2.17	5.50	73.84	1.41	12.36	7502	7378	7398	—1.70	—1.40
	Average	.....	6.18	37.15	48.80	7.87	3.26	5.44	68.65	1.26	13.52	6988	6911	6988	—1.10	0

MIDDLE KITTANNING OR NO. 6 COAL.

Publication No.	County.	Township.	Moisture at 105° C.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific value determined.	Calorific value calculated by Dulong's formula.	Calorific value calculated from "H" = 8243.	Variation of value by Dulong's formula from actual determination.	Variation of value from "H" from actual determination.
															Percent.	Percent.
136	Lawrence	Perry	5.99	39.05	50.14	4.82	3.61	5.56	71.82	1.33	12.86	7314	7248	7135	—0.90	—2.40
82a	"	"	6.64	34.28	48.16	10.92	3.32	5.16	64.95	1.23	14.42	6626	6483	6597	—2.20	—0.40
82b	Gallia	Greenfield	8.08	37.53	45.87	8.52	3.64	5.48	65.71	1.18	15.47	6717	6614	6657	—1.50	—0.90
89a	Athens	Canaan	6.36	34.19	50.96	8.49	0.51	5.40	69.25	1.43	14.92	6919	6822	6988	—1.40	+1.00
83	"	Athens	6.17	36.40	49.61	7.82	0.90	5.43	69.22	1.30	15.33	6868	6823	7036	—0.70	+2.40
84	"	Waterloo	6.70	35.36	51.19	6.75	2.28	5.49	69.21	1.18	15.09	6921	6885	6997	—0.50	+1.10
85	"	"	6.80	36.90	48.25	8.05	2.14	5.49	67.40	1.37	15.55	6794	6717	6891	—1.10	+1.40
82	Vinton	Swan	4.90	39.16	45.79	10.15	4.25	5.40	66.26	1.23	12.71	6845	6762	6748	—1.20	—1.40
81	Hocking	Starr	6.52	38.30	47.15	8.03	3.52	5.49	67.33	1.20	14.43	6850	6792	6832	—0.80	—0.20
89	Athens	Dover	7.14	34.22	51.92	6.72	1.65	5.56	69.32	1.30	15.45	6863	6889	7001	+0.40	+2.00
90	"	Trimble	7.28	32.38	53.61	6.73	0.86	5.45	69.46	1.34	16.16	6894	6813	7036	—1.20	+2.10
86	Hocking	Ward	7.55	34.03	52.57	5.85	0.77	5.52	70.05	1.42	16.39	6950	6874	7092	—1.10	+2.00
87	"	"	7.45	35.01	52.73	4.81	0.66	5.53	71.04	1.43	16.53	7057	6949	7193	—1.50	+1.90
88	"	"	7.40	34.17	53.43	5.00	1.06	5.55	70.58	1.32	16.49	7027	6930	7157	—1.40	+1.80
80	"	Green	6.55	37.30	49.18	6.97	2.57	5.45	68.40	1.18	15.43	6901	6798	6975	—1.50	+1.10
79	Perry	Salt Lick	7.76	33.50	51.27	7.47	1.45	5.46	68.30	1.18	16.14	6772	6737	6901	—0.50	+1.90
91	"	Monroe	6.79	35.45	51.85	5.91	1.00	5.49	70.30	1.30	16.00	6983	6906	7137	—1.10	+2.20
78	"	Pike	7.00	37.12	48.93	6.95	2.33	5.58	68.29	1.26	15.59	6880	6821	6953	—0.90	+1.10
92	"	"	5.25	38.85	46.04	9.86	3.43	5.38	66.05	1.18	14.10	6773	6663	6792	—1.60	+0.30
93	"	Bearfield	5.90	36.58	47.42	10.10	4.96	5.26	65.43	1.22	13.03	6686	6649	6627	—0.60	—0.90
95	"	Clay	6.72	38.30	48.34	6.64	2.43	5.61	68.45	1.29	15.58	6903	6847	6996	—0.80	+1.30
94	"	Harrison	7.21	37.60	49.93	5.26	2.34	5.60	69.77	1.26	15.77	7008	6942	7075	—0.90	+1.00
97	"	"	5.70	38.83	47.02	8.45	3.38	5.37	67.77	1.18	13.85	6851	6807	6874	—0.60	+0.30

MIDDLE KITTANNING OR NO. 6 COAL.

Publication No.	County.	Township.	Moisture at 105° C.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific value determined.	Calorific value calculated by Dulong's formula.	Calorific value calculated from "H" = 8243.	Variation of value by Dulong's formula from actual determination. Percent.	Variation of value from "H" from actual determination. Percent.
98	"	"	6.40	38.00	48.02	7.58	2.72	5.49	68.06	1.26	14.89	6867	6811	6927	—0.80	+0.90
101	Muskingum	Brush Creek	5.08	39.75	45.40	9.77	5.54	5.32	65.74	1.14	12.49	6802	6732	6687	—1.00	—1.70
100	"	Harrison	4.67	40.32	45.18	9.83	4.10	5.38	67.71	1.16	11.82	6873	6838	6802	—0.50	—1.00
96	"	Newton	5.02	38.16	47.26	9.56	5.97	5.29	65.88	1.12	12.18	6758	6757	6683	0	—1.10
99	"	Washington	5.44	39.15	46.13	9.28	3.77	5.34	67.16	1.18	13.27	6822	6781	6804	—0.60	—0.30
104	"	Muskingum	5.55	40.27	48.95	5.23	3.63	5.57	70.54	1.26	13.77	7191	7108	7137	—1.00	—0.80
102	"	Madison	4.75	39.88	46.09	9.28	5.35	5.35	66.69	1.28	12.05	6854	6834	6766	—0.30	—1.30
103	"	"	4.62	40.95	47.85	6.58	4.49	5.47	69.58	1.30	12.58	7126	7066	7051	—0.80	—1.10
111	Coshocton	Linton	4.37	40.97	49.30	5.36	3.61	5.56	71.34	1.28	12.85	7247	7207	7224	—0.60	—0.30
112	"	"	10.93	34.00	48.43	6.64	2.03	5.37	63.08	1.15	21.73	6133	6054	6673	—1.30	+8.80
108	"	Franklin	4.33	41.11	48.97	5.59	4.00	5.41	71.42	1.22	12.36	7269	7194	7186	—1.00	—1.10
109	"	Virginia	5.12	38.99	48.87	7.02	3.87	5.45	69.49	1.20	12.97	7066	7022	7010	—0.60	—0.80
105	"	Jackson	5.32	40.93	47.45	6.30	4.22	5.50	69.29	1.24	13.45	7086	7010	7032	—1.10	—0.80
110	"	Lafayette	5.60	34.69	46.43	13.28	4.87	4.95	61.59	1.08	14.23	6222	6179	6395	—0.70	+2.80
113	"	Oxford	4.44	40.71	50.40	4.45	3.54	5.53	72.65	1.35	12.48	7351	7318	7298	—0.40	—0.70
114	"	Adams	4.58	39.18	47.49	8.75	5.36	5.40	67.51	1.24	11.74	6878	6930	6823	+0.80	—0.80
118	"	White Eyes	5.32	37.39	48.69	8.60	4.36	5.32	67.41	1.18	13.13	6828	6813	6834	—0.20	+0.10
120	"	"	4.50	38.73	50.80	5.97	3.63	5.53	70.94	1.30	12.63	7173	7174	7163	0	—0.10
107	"	Keene	5.40	39.92	49.60	5.08	3.18	5.58	70.90	1.24	14.02	7194	7121	7189	—1.00	—0.10
133	Tuscarawas	Salem	3.45	40.02	48.86	7.67	5.22	5.30	70.02	1.26	10.53	7135	7148	7013	+0.20	—1.70
131	"	Clay	3.41	39.73	47.48	9.38	4.88	5.23	68.77	1.30	10.44	6971	7018	6896	+0.70	—1.10
115	"	Jefferson	4.72	40.30	49.51	5.47	4.05	5.53	71.08	1.32	12.55	7199	7199	7160	0	—0.50
130	"	Mill	3.78	38.27	49.53	8.42	3.83	5.26	70.31	1.22	10.96	7101	7108	7008	+0.10	—1.30

MIDDLE KITTANNING OR NO. 6 COAL.

129	" ...	Union	3.81	38.71	51.47	6.01	3.24	5.41	72.30	1.36	11.68	7306	7276	7239	—0.40	—0.90
124	" ...	Warwick	4.10	41.64	49.05	5.21	3.25	5.57	72.45	1.42	12.10	7331	7326	7281	—0.10	—0.70
134	" ...	York	3.18	43.56	46.33	6.93	4.12	5.50	71.13	1.28	11.04	7305	7260	7163	—0.60	—1.90
116	" ..	Bucks	5.19	40.79	48.15	5.87	3.55	5.59	70.12	1.36	13.51	7122	7090	7119	—0.40	0
128	" ...	Auburn	4.30	40.07	48.00	7.63	3.97	5.41	69.39	1.28	12.32	7001	7030	7021	+0.40	+0.30
117	Coshocton	Crawford	4.70	39.20	44.81	11.29	5.60	5.23	64.78	1.12	11.98	6594	6647	6589	+0.80	—0.10
106	"	Clark	5.30	39.08	49.47	6.15	3.72	5.50	69.59	1.12	13.92	7084	7003	7077	—1.10	—0.10
121	Tuscarawas ...	Dover	3.52	40.25	50.22	6.01	3.17	5.41	72.13	1.28	12.00	7297	7248	7267	—0.70	—0.40
122	" ...	"	4.94	36.20	49.36	9.50	4.19	5.14	67.54	1.30	12.33	6856	6793	6801	—0.90	—0.80
123	" ...	Goshen	3.51	41.60	47.20	7.69	4.56	5.45	70.26	1.22	10.82	7153	7192	7047	+0.50	—1.50
132	Carroll	Orange	3.76	39.11	50.34	6.79	3.06	5.36	71.99	1.40	11.40	7238	7241	7190	0	—0.70
138	Tuscarawas ...	Fairfield	7.15	38.34	49.95	4.56	2.62	5.64	71.29	1.23	14.66	7194	7129	7121	—0.90	—1.00
127	" ...	"	4.66	39.25	49.87	6.22	3.28	5.48	70.80	1.28	12.94	7097	7126	7150	+0.40	+0.70
119	Holmes	Walnut Creek.	7.31	34.92	53.56	4.21	1.00	5.42	70.62	1.44	17.31	6952	6852	7234	—1.40	+4.10
125	Tuscarawas ...	Lawrence	4.69	39.57	46.68	9.06	4.70	5.30	67.59	1.24	12.11	6881	6873	6828	—0.10	—0.80
126	" ...	Sandy	4.92	38.13	49.91	7.04	2.91	5.40	70.45	1.28	12.92	7082	7062	7082	—0.30	0
135	Stark	Sandy	6.66	36.24	48.88	8 22	2.66	5.37	68.94	1.20	13.61	6977	6897	6857	—1.10	—1.70
137	Columbiana ...	Liverpool	3.60	36.16	55.64	4.60	1.76	5.46	77.06	1.38	9.74	7789	7728	7462	—0.80	—4.20
139	Stark	Minishillen ...	5.65	38.51	45.76	10.08	4.13	5.29	66.92	1.19	12.39	6868	6791	6699	—1.10	—2.50
	Average	.....	5.56	38.11	48.96	7.36	3.30	5.43	69.03	1.26	13.62	6980	6935	6980	—0.60	0

UPPER FREEPORT, WATERLOO OR NO. 7 COAL.

Publication No.	County.	Township.	Moisture at 105° C.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific value determined.	Calorific value calculated by Dulong's formula.	Calorific value calculated from "H" = 8074.	Variation of value by Dulong's formula from actual determination.	Variation of value from "H" from actual determination.
															Percent.	Percent.
147	Lawrence	Lawrence	7.20	32.25	49.88	10.67	2.33	5.03	65.03	1.25	15.69	6556	6365	6496	—2.90	—0.90
144	"	Aid	7.85	32.90	47.07	12.18	2.66	5.09	63.03	1.25	15.79	6305	6228	6302	—1.20	0
145	"	"	8.37	31.80	51.60	8.23	1.29	5.21	66.94	1.31	17.02	6596	6502	6658	—1.40	+0.90
146	"	"	8.45	31.25	49.02	11.28	0.93	5.10	65.20	1.28	16.21	6405	6348	6427	—0.90	+0.30
142	Gallia	Walnut	7.62	32.85	47.14	12.39	1.81	5.19	63.48	1.28	15.85	6371	6276	6353	—1.50	—0.30
140	Lawrence	Symmes	7.13	33.65	50.31	8.91	1.31	5.33	67.09	1.28	16.08	6716	6595	6703	—1.80	—0.20
141	"	"	8.77	31.70	50.82	8.71	0.76	5.32	66.88	1.25	17.08	6586	6520	6618	—1.00	+0.50
143	"	"	8.38	31.45	49.97	10.09	1.84	5.18	64.90	1.27	16.72	6497	6351	6477	—2.30	—0.30
	Average	.....	7.97	32.23	49.48	10.31	1.62	5.18	65.32	1.28	16.30	6504	6398	6504	—1.60	0

UPPER FREEPORT OR NO. 7 COAL.

Publication No.	County.	Township.	Moisture at 105° C.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific value determined.	Calorific value calculated by Dulong's formula.	Calorific value calculated from "H" = 8280.	Variation of value by Dulong's formula from actual determination.	Variation of value from "H" from actual determination.
															Percent.	Percent.
148	Muskingum ...	Harrison	4.89	42.35	44.98	7.78	4.36	5.53	67.74	1.17	13.42	6944	6899	6968	—0.60	+0.30
149	" ...	Brush Creek..	4.72	43.47	44.25	7.56	5.00	5.55	68.27	1.32	12.30	7046	7010	6962	—0.50	—1.20
150	" ...	Wayne	5.11	35.50	46.79	12.60	3.84	5.11	64.81	1.25	12.39	6558	6551	6582	—0.10	+0.30
151	Coshocton	Clark	6.40	37.92	52.49	3.19	2.01	5.67	72.72	1.25	15.16	7325	7217	7365	—1.50	+0.70
	Average	.....	5.28	39.81	47.13	7.78	3.80	5.47	68.38	1.25	13.32	6968	6919	6969	—0.70	0

PITTSBURG OR NO. 8 COAL.

Publication No.	County.	Township.	Moisture at 105° C.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific value determined.	Calorific value calculated by Dulong's formula.	Calorific value calculated from "H". "H" = 8363.	Variation of value by Dulong's formula from actual determination	Variation of value from "H" from actual determination.
															Percent.	Percent.
25	Gallia	Ohio	5.80	36.76	47.38	10.06	4.34	5.16	64.94	1.10	14.40	6551	6504	6772	—0.70	+3.40
27	"	Harrison	6.98	36.14	47.85	9.03	5.21	5.24	64.91	1.01	14.60	6583	6540	6705	—0.70	+1.90
28	"	"	7.83	34.15	48.26	9.76	3.89	5.18	64.59	1.09	15.49	6544	6423	6655	—1.90	+1.70
26	"	Green	6.73	34.34	45.90	13.03	4.37	5.11	62.30	1.14	14.05	6356	6287	6443	—1.10	+1.40
23	Athens	Ames	5.78	37.43	48.79	8.00	4.19	5.14	67.55	0.95	14.17	6833	6714	6954	—1.70	+1.80
24	"	Berne	6.60	35.05	48.15	10.20	3.41	5.13	66.61	0.93	13.72	6607	6639	6750	+0.50	+2.20
24	"	"	4.51	38.24	45.76	11.49	4.88	5.10	65.92	0.99	11.62	6636	6691	6727	+0.80	+1.40
22	Morgan	Homer	6.87	40.55	44.39	8.19	4.22	5.32	67.39	0.90	13.98	6722	6770	6846	+0.70	+1.80
9	Belmont	Washington ..	2.79	37.88	49.91	9.42	5.09	5.25	69.76	1.09	9.39	7215	7156	7031	—0.80	—2.60
11	"	Somerset	4.08	37.08	48.23	10.61	4.95	4.89	68.77	1.10	9.68	6931	6937	6831	+0.10	—1.40
8	"	Mead	2.91	37.94	51.15	8.00	4.31	5.11	72.95	1.04	8.59	7340	7386	7187	+0.60	—2.10
3	"	Pultney	3.51	38.65	50.98	6.86	3.76	5.45	72.06	1.17	10.70	7325	7322	7266	0	—0.80
4	"	"	3.80	37.18	50.07	8.95	4.27	5.23	70.57	1.20	9.78	7103	7181	7036	+1.10	—0.90
7	"	Smith	3.21	36.82	52.71	7.26	4.28	5.14	71.49	1.06	10.77	7297	7177	7225	—1.60	—1.00
10	"	Warren	4.47	37.53	46.99	11.01	4.67	5.17	67.64	1.08	10.43	6875	6908	6783	+0.50	—1.30
6	"	Union	3.75	37.99	47.42	10.84	4.76	5.09	67.41	1.11	10.79	6865	6844	6852	—0.30	—0.20
5	"	"	4.46	36.00	48.78	10.76	4.45	4.85	68.24	1.10	10.60	6903*	6825	6818	—1.10	—1.20
1	"	Pease	3.39	36.84	51.91	7.86	2.97	5.21	71.45	1.24	11.27	7217	7148	7241	—1.00	+0.30
2	"	Colerain	3.79	36.37	50.84	9.00	4.16	5.14	70.41	1.09	10.20	7145	7114	7039	—0.40	—1.50
6a	"	Wheeling	4.25	33.53	51.87	10.35	3.95	5.19	68.17	1.09	11.25	6903	6900	6901	0	0
2a	"	Flushing	4.23	36.34	50.22	9.21	4.17	5.14	68.75	1.09	11.64	7003	6919	6984	—1.20	—0.30
12	Jefferson	Mt. Pleasant..	3.10	37.92	49.46	9.52	3.83	5.22	69.56	1.10	10.77	7153	7042	7074	—1.60	—1.10
15	"	Warren	3.13	37.88	50.77	8.22	4.02	5.38	71.03	1.26	10.09	7233	7246	7168	+0.20	—0.90
15a	"	"	4.57	32.40	54.03	9.00	1.55	5.06	71.18	1.32	11.89	7105	7017	7133	—1.30	+0.40

PITTSBURG OR NO. 8 COAL.

18	Harrison	Short Creek ..	6.54	35.48	51.24	6.74	2.19	5.70	70.49	1.22	13.66	7061	7119	7118	+0.80	+0.80
21	"	Athens	5.98	34.35	53.70	5.97	1.35	5.44	72.22	1.31	13.71	7202	7145	7281	—0.80	+1.10
20	"	Cadiz	3.83	36.70	48.59	10.88	4.38	5.09	67.70	1.27	10.68	6864	6861	6865	0	0
16	Jefferson	Wells	4.89	33.10	51.55	10.46	4.09	5.03	68.01	1.12	11.29	6953	6833	6829	—1.70	—1.80
13	"	Smithfield	4.96	34.51	54.08	6.45	1.75	5.37	72.43	1.33	12.67	7277	7199	7301	—1.10	+0.30
19	"	" ...	4.18	36.95	50.65	8.22	2.83	5.36	71.20	1.26	11.13	7160	7180	7153	+0.30	—0.10
14	"	" ...	4.30	35.28	52.54	7.88	3.01	5.18	71.34	1.20	11.39	7144	7125	7160	—0.30	+0.20
17	"	Wayne	5.05	35.88	51.12	7.95	2.61	5.32	70.68	1.25	12.19	7147	7076	7116	—1.00	—0.40
	Average	.....	4.70	36.35	49.87	9.10	3.81	5.20	68.99	1.13	11.17	6977	6945	6976	—0.50	0

Calorific value and ultimate analysis on these two samples low — see note accompanying analytical samples given in field report.

POMEROY OR NO. 8a COAL.

Publication No.	County.	Township.	Moisture at 105° C.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific value determined.	Calorific value calculated by Dulong's formula.	Calorific value calculated from "H" "H" = 8156.	Variation of value by Dulong's formula from actual determination.	Variation of value from "H" from actual determination.
															Percent.	Percent.
34	Gallia	Chesire	8.21	34.23	46.10	11.46	2.18	5.48	62.95	1.02	16.91	6387	6297	6423	—1.40	+0.60
33	Meigs	Sutton	4.85	36.28	46.35	12.52	2.94	5.32	65.29	1.17	12.76	6624	6624	6565	0	—0.90
29	"	Salisbury	7.33	34.59	49.39	8.69	2.05	5.53	66.71	1.06	15.96	6725	6655	6728	—1.00	0
30	"	"	7.22	32.82	50.67	9.29	1.32	5.39	66.47	1.10	16.43	6668	6551	6732	—1.80	+1.00
31	"	"	5.51	38.19	45.72	10.58	4.17	5.40	65.55	0.95	13.35	6661	6677	6597	+0.20	+1.00
32	"	Rulland	7.63	33.33	48.11	10.93	1.83	5.20	65.29	1.03	15.72	6512	6431	6534	—1.20	+0.30
	Average	.....	6.79	34.91	47.72	10.58	2.42	5.39	65.38	1.06	15.19	6596	6539	6596	—0.90	0

MEIGS CREEK OR NO. 9 COAL.

Publication No.	County.	Township.	Moisture at 105° C.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calorific value determined.	Calorific value calculated by Dulong's formula.	Calorific value calculated from "H". "H" = 8379.	Variation of value by Dulong's formula from actual determination. Percent.	Variation of value from "H" from actual determination. Percent.
53	Washington ..	Adams	2.95	37.47	46.69	12.89	5.55	5.05	65.88	0.92	9.71	6803	6773	6712	—0.40	—1.30
52	" ..	Aurelius	3.40	37.95	49.07	9.58	5.03	5.31	68.33	0.90	10.85	7083	6998	6983	—1.20	—1.40
44	Noble	Elk	3.06	38.43	46.18	12.33	6.00	5.11	66.18	0.86	9.53	6865	6834	6722	—0.50	—2.10
45	"	Enoch	2.90	37.24	49.70	10.16	4.27	5.22	68.53	1.04	10.78	7051	6968	7023	—1.20	—0.40
43	"	Stock	2.55	38.40	47.64	11.41	5.79	5.11	67.50	0.92	9 27	6952	6947	6854	—0.10	—1.40
42	"	Marion	3.12	37.36	46.67	12.85	5.60	5.09	65.61	0.92	9.93	6739	6755	6698	+0.20	—0.60
50	Morgan	Meigsville ...	5.13	36.07	47.06	11.74	4.89	5.06	64.77	0.87	12.67	6625	6541	6666	—1.30	+0.60
48	"	Bristol	5.05	37.83	46.75	10.37	4.30	5.14	67.04	0.89	12.26	6730	6757	6823	+0.40	+1.40
49	"	Manchester ..	4.07	37.61	47.66	10.66	5.07	5.10	66.19	0.87	12.11	6779	6698	6834	—1.20	+0.80
47	Noble	Brookfield ...	3.54	37.41	45.82	13.23	6.21	5.12	64.44	0.88	10.12	6642	6679	6593	+0.60	—0.70
46	"	" ...	4.85	37.28	48.05	9.82	5.59	5.26	66.01	0.97	12.35	6834	6738	6807	—1.40	—0.40
37	Belmont	Warren	4.47	35.31	47.15	13.07	3.27	4.99	65.83	1.13	11.71	6668	6607	6709	—0.90	+0.60
40	"	Goshen	3.40	35.72	45.94	14.94	4.39	4.86	64.77	1.08	9.96	6578	6576	6573	0	—0.10
41	"	Smith	3.52	34.74	49.90	11.84	3.67	5.02	67.36	1.05	11.06	6884	6778	6867	—1.50	—0.20
39	"	Union	4.17	35.09	51.14	9.60	3.11	4.97	69.90	1.09	11.33	7001	6943	7035	—0.80	+0.50
38	"	"	4.31	32.47	51.54	11.68	1.94	5.09	68.32	1.11	11.86	6837	6805	6920	—0.50	+1.20
36a	"	Wheeling	7.52	31.75	49.49	11.24	2.11	5.14	66.41	1.11	13.99	6589	6584	6678	—0.10	+1.40
36	"	Flushing	4.98	33.30	48.90	12.82	2.41	4.95	66.31	1.19	12.32	6652	6584	6740	—1.00	+1.30
35	Harrison	Athens	5.35	33.09	51.27	10.29	2.20	5.21	68.67	1.25	12.38	6885	6860	6933	—0.40	+0.70
	Average	.....	4.11	36.03	48.26	11.60	4.28	5.09	66.74	1.00	11.29	6800	6759	6800	—0.60	0

LABORATORY TESTS ON THE NO. 8 COAL TO DETERMINE ITS SUITABILITY FOR IMPROVEMENT BY WASHING.

The object of coal washing is to remove the impurities—ash and pyrites—from the coal by taking advantage of their greater specific gravity. The various forms of apparatus in use all depend upon the principle that coal being lighter can be carried away by moving water while the heavy impurities—slate and pyrites—are left behind. In order that a coal may be benefited by this treatment two things are necessary:

In the first place, the pyrites and the slate must be so distributed that by crushing the coal to a reasonable fineness they may be broken away from the pieces of coal. Second, the coal left must be purified enough to make the expense of the process worth while. In order to test these points what are known as "float and sink" tests are made in the laboratory, the coal being crushed sufficiently small and then separated by sifting into two or three sizes, these sizes are then stirred up in a heavy liquid of such specific gravity that the coal will float upon it while the impurities will sink. In this way the coal is separated from the free pyrites and slate, the relative amounts weighed and the products analyzed to ascertain the degree of purification.

In the experiments the following routine was adopted. The coal was crushed so that it would pass a one-half inch screen. The crushed coal was then freed from dust by separating from it all that would pass a one-sixtieth inch screen. This is best done by, first, screening on a twenty-mesh sieve and then screening what passes through the twenty-mesh on a sixty-mesh, subsequently adding the oversize of the sixty-mesh to the oversize of the twenty-mesh. The portion of coal passing through the sixty-mesh sieve amounting to from one to four per cent. of the total weight of the sample was not treated farther as the separation by gravity is very unsatisfactory on this dust. The solutions used in the separation were, first, calcium chloride of 1.35 specific gravity, and second, zinc chloride solution of 1.45 specific gravity.

Coking tests were made upon the coal on both the separated and the unseparated samples. The laboratory method of making the coking test is as follows: Two clay crucibles are selected of such size that one sets easily inside the other. Convenient sizes are a 20-gram Denver fire-clay for the inner and a larger 5 Hessian for the outer. The inner crucible is provided with a closely fitting cover. The larger crucible is put into a wind furnace and heated to a bright red. Meanwhile the smaller one is charged about two-thirds full with coal crushed to about ¼ inch mesh. (Using the 20-gram Denver crucible one hundred grams of coal can be weighed out for the charge.) The cover is placed on the smaller crucible and it is set inside the larger one. A little coarse coal is thrown on top of it and the cover placed on the larger crucible. At the end of an hour

both are removed from the furnace. A little more coal is put into the outer crucible and it is allowed to cool covered. The placing of the coal in the outer crucible is to prevent oxygen getting into the coke and burning out sulphur.

The results of the washing and coking tests are given in the following tables. The results may perhaps best be understood by consideration of some particular sample, as No. 4. In this sample the percentages of ash and sulphur in the unwashed coal are respectively 9.12 and 4.35. The sample crushed to ½ inch was separated by sifting into 96.9 coarser and 3.1 per cent. finer than 60-mesh. This coarser portion treated on a solution of 1.35 specific gravity resulted in a separation into 81.15 per cent. of light coal which analyzed 5.09 per cent. ash and 2.63 per cent. sulphur. The heavier portion analyzed 25.74 per cent. ash and 11.04 per cent. sulphur. 5.09 per cent. of ash in the light product shows the possibility of producing a washed coal low in ash. The washing loss—14.99 per cent.—heavier than 1.35, is larger than desirable, but results upon samples No. 12 and No. 11 washed on a solution of 1.45 specific gravity indicate that the ash might be reduced to about 7 per cent. with a washing loss of probably only 6 or 7 per cent. An improvement of 2 per cent. in ash accompanied by decided lowering of the sulphur with a washing loss of only 6 or 7 per cent. indicates the commercial possibility of putting washed coal from this region upon the market.

Coking tests were made upon both the raw or unwashed coal and upon the washed product and the yield and ash and sulphur contents determined. The coke yield in this unwashed sample is 62 per cent. analyzing 13.35 per cent. ash and 3.47 per cent. sulphur. The coke yield from the washed product is 59.2, which analyses 9.36 per cent. ash and 1.91 per cent. sulphur.

All of the samples show a decided lowering in ash by washing and a considerable lowering of the amount of sulphur. In most of the samples, however, a large amount of sulphur seems to be present as an inherent part of the coal and cannot be removed by washing. The ash was very light colored in most of the samples which indicates that only a portion of the sulphur was present as pyrites. Sample No. 29 deserves special notice. The original coal contains 8.94 per cent. ash and 2.11 per cent. sulphur. The washed coal shows only 6.16 per cent. ash and 1.14 percent. sulphur. The coke from the washed coal analyzes only 10.35 percent. ash and .93 per cent. sulphur and compares in these respects very favorably with Connellsville coke. The production of high-grade blast furnace coke from washed coals from some of these mines appears not at all unlikely, while every sample tested shows the possibility of producing from these seams washed coal low in ash.

The extent to which the sulphur in the coal is expelled in coking is a matter of interest. In the table of results which follow is given the percentage of the total sulphur in the original coal which is retained in

the coke produced. The result is obtained by multiplying the percentage yield of the coke by the percentage of sulphur in the coke and dividing the product by the percentage of sulphur in the coal.

Publication No. 12.

Unwashed coal, ash 9.61, sulphur 3.86.

	Portion	Ash	Sulphur	Compared with original sample	
				Ash	Sulphur
$\frac{1}{2}$ inch to $\frac{1}{60}$ inch = ...	94.5	.....	.....	.....	.....
Lighter than 1.35 = ...	74.9	5.48	3.17	4.10	2.37
Heavier than 1.35 = ...	19.6	24.23	6.23	4.75	1.22
$\frac{1}{60}$ inch and finer = ...	4.1	.....	.....	0.39	0.16
				9.24	3.75
$\frac{1}{2}$ inch to $\frac{1}{60}$ inch = ...	97.7	.....	.....	.....	.....
Lighter than 1.45 = ...	90.1	7.12	3.60	6.42	3.24
Heavier than 1.45 = ...	7.6	37.73	6.64	2.87	0.50
$\frac{1}{60}$ inch and finer = ...	2.0	.....	.....	0.19	0.08
				9.48	3.82

Coke.

	Percentage yield	Ash	Sulphur
Coke from unwashed coal = ...	61.9	14.58	3.36
Percentage of the sulphur in the coal left in the coke = 53.6%.			
Coke from washed coal lighter than sp. gr. 1.45 = ...	60.2	12.37	3.22
Percentage of the sulphur in the coal left in the coke = 53.8%.			

Publication No. 19.

Unwashed coal, ash 8.35, sulphur 2.88.

	Portion	Ash	Sulphur	Compared with original sample	
				Ash	Sulphur
$\frac{1}{2}$ inch to $\frac{1}{60}$ inch = ...	94.49	.....	.....	.....	.....
Lighter than 1.35 = ...	82.42	5.83	2.55	4.81	2.10
Heavier than 1.35 = ...	12.07	29.06	7.09	3.51	0.86
$\frac{1}{60}$ inch and finer = ...	4.69	.....	.....	0.39	0.14
		.....		8.71	3.10

Publication No. 19.

Coke.

	Percentage yield	Ash	Sulphur		
Coke from unwashed coal=....	62.00	15.63	2.47		
Percentage of the sulphur in the coal left in the coke = 53.2%.					
Coke from washed coal lighter than 1.35 = ...	59.03	11.32	2.12		
Percentage of the sulphur in the coal left in the coke = 49.0%.					

Publication No. 4.

Unwashed coal, ash 9.12, sulphur 4.35.

	Portion	Ash	Sulphur	Compared with original sample	
				Ash	Sulphur
½ inch to $\frac{1}{60}$ inch =.....	96.14	.....	.....	.....	.....
Lighter than 1.35 = ...	81.15	5.09	2.63	4.13	2.13
Heavier than 1.35 =.....	14.99	25.74	11.04	3.86	1.65
$\frac{1}{60}$ inch and finer =.....	3.1	.....	.....	0.28	0.13
				8.27	3.91

Coke.

	Percentage yield	Ash	Sulphur		
Coke from unwashed coal =...	62.00	13.35	3.47		
Percentage of the sulphur in the coal left in the coke = 49.4%.					
Coke from washed coal lighter than 1.35 =.....	59.29	9.36	1.91		
Percentage of the sulphur in the coal left in the coke = 43.0%.					

Publication No. 10.

Unwashed coal, ash 11.25, sulphur 4.77.

	Portion	Ash	Sulphur	Compared with original sample	
				Ash	Sulphur
½ inch to $\frac{1}{60}$ inch =.....	96.00	.....	.....	.....	.....
Lighter than 1.35 = ...	74.75	6.67	3.82	4.99	2.86
Heavier than 1.35 =.....	21.25	23.04	7.86	4.90	1.67
$\frac{1}{60}$ inch and finer =.....	3.43	.....	.....	0.39	0.16
				10.28	4.69

Publication No. 11.

Unwashed coal, ash 10.81, sulphur 5.04.

	Portion	Ash	Sulphur	Compared with original sample	
				Ash	Sulphur
$\frac{1}{2}$ inch to $\frac{1}{60}$ inch =	94.52	.....	.....	.....	.....
Lighter than 1.35 =	66.7	6.48	3.68	4.32	2.45
Heavier than 1.35 =	27.82	21.05	8.83	5.86	2.46
$\frac{1}{60}$ inch and finer =	4.62	.....	.....	0.50	0.23
				10.68	5.14
$\frac{1}{2}$ inch to $\frac{1}{60}$ inch =	96.9	.....	.....	.....	.....
Lighter than 1.45 =	87.3	7.83	4.20	6.84	3.67
Heavier than 1.45 =	9.6	33.88	14.24	3.25	1.37
$\frac{1}{60}$ inch and finer =	2.2	.....	.....	0.24	0.11
				10.33	5.15

Publication No. 5.

Unwashed coal, ash 10.98, sulphur 4.54.

	Portion	Ash	Sulphur	Compared with original sample	
				Ash	Sulphur
$\frac{1}{2}$ inch to $\frac{1}{60}$ inch =	96.0	.....	.....	.....	.....
Lighter than 1.35 =	74.15	6.90	3.40	5.12	2.52
Heavier than 1.35 =	21.85	24.64	8.55	5.38	1.87
$\frac{1}{60}$ inch and finer =	3.35	.....	.....	0.37	0.15
				10.87	4.54

Publication No. 9.

Unwashed coal, ash 9.50, sulphur 5.13.

	Portion	Ash	Sulphur	Compared with original sample	
				Ash	Sulphur
$\frac{1}{2}$ inch to $\frac{1}{60}$ inch =	97.0	.....	.....	.....	.....
Lighter than 1.35 =	75.6	6.93	3.82	5.24	2.89
Heavier than 1.35 =	21.4	19.31	9.26	4.13	1.98
$\frac{1}{60}$ inch and finer =	2.0	.....	.....	0.19	0.10
				9.56	4.97

Coke.

	Percentage yield	Ash	Sulphur	Phos.
Coke from unwashed coal = ...	59.32	16.22	4.42	.0067
Percentage of the sulphur in the coal left in the coke = 51.1%.				
Coke from washed coal lighter than 1.35	57.6	12.23	3.24	.0036
Percentage of the sulphur in the coal left in the coke = 48.8%.				

Publication No. 8.

Unwashed coal, ash 8.07, sulphur 4.35.

	Portion	Ash	Sulphur	Compared with original sample	
				Ash	Sulphur
½ inch to 1/60 inch = ...	96.9	.....	.....	.....	.....
Lighter than 1.35 = ...	81.5	5.68	3.22	4.63	2.62
Heavier than 1.35 = ...	15.4	24.58	11.44	3.79	1.76
1/60 inch and finer = ...	2.8	.....	.....	0.23	0.12
				8.65	4.50

Coke.

	Percentage yield	Ash	Sulphur	Phos.
Coke from unwashed coal = ...	60.6	14.36	4.01	.0125
Percentage of the sulphur in the coal left in the coke = 55.9%.				
Coke from washed coal lighter than 1.35	58.7	10.00	2.71	.0056
Percentage of the sulphur in the coal left in the coke = 49.4%.				

Publication No. 29.

Unwashed coal, ash 8.94, sulphur 2.11.

	Portion	Ash	Sulphur	Compared with original sample	
				Ash	Sulphur
½ inch to 1/60 inch = ...	99.3	.....	.....	.....	.....
Lighter than 1.35 = ...	85.5	6.16	1.14	5.27	0.97
Heavier than 1.35 = ...	13.8	27.64	8.83	3.81	1.22
1/60 inch and finer = ...	0.5	.....	.....	0.04	0.01
				9.12	2.20

Coke.

	Percentage yield	Ash	Sulphur	Phos.	
Coke from unwashed coal = ...	59.86	15.54	1.80		
Percentage of the sulphur in the coal left in the coke = 51.1%.					
Coke from washed coal lighter than 1.35 = ...	59.80	10.35	0.93	.016	
Percentage of the sulphur in the coal left in the coke = 48.8%.					

Publication No. 25.

Unwashed coal, ash 10.19, sulphur 4.40.

	Portion	Ash	Sulphur	Compared with original sample	
				Ash	Sulphur
½ inch to $\frac{1}{60}$ inch = ...	97.6	.....	.....	.....	.....
Lighter than 1.35 = ...	59.4	5.32	2.73	3.18	1.62
Heavier than 1.35 = ...	38.2	18.87	6.94	7.21	2.65
$\frac{1}{60}$ inch and finer = ...	1.45	.....	.....	0.15	0.06
				10.54	4.33

Coke.

	Percentage yield	Ash	Sulphur		
Coke from unwashed coal = ...	58.66	17.15	3.60		
Percentage of the sulphur in the coal left in the coke = 48.0%.					
Coke from washed coal lighter than 1.35	57.7	9.32	2.12		
Percentage of the sulphur in the coal left in the coke = 44.8%.					

Publication No. 27.

Unwashed coal, ash 9.17, sulphur 5.29.

	Portion	Ash	Sulphur	Compared with original sample	
				Ash	Sulphur
½ inch to $\frac{1}{60}$ inch = ...	95.5	.....	.....	.....	.....
Lighter than 1.35 = ...	72.0	4.93	3.11	3.55	2.24
Heavier than 1.35 = ...	23.50	23.58	11.00	5.54	2.59
$\frac{1}{60}$ inch and finer = ...	3.4	.....	.....	0.31	0.18
				9.40	5.01

Coke.

	Percentage yield	Ash	Sulphur		
Coke from unwashed coal = ...	59.15	15.56	4.49		
Percentage of the sulphur in the coal left in the coke = 50.2%.					
Coke from washed coal lighter than 1.35	56.50	8.94	2.53		
Percentage of the sulphur in the coal left in the coke = 46.0%.					

CHAPTER IX.

CHEMICAL WORK.

BY PROFESSOR E. E. SOMERMEIER, OHIO STATE UNIVERSITY.

Sampling. The analyses given in this report are all upon mine samples personally taken by representatives of the Survey. A few were collected by Professor Orton, a few by the writer and a few by Mr. D. D. Condit. The greater number were, however, taken by Professor B. A. Eisenlohr and Mr. Jesse E. Hyde, both of whom by their training and experience were unusually well fitted for the work, and their painstaking care in collecting and selecting the samples deserves special acknowledgment.

The method of collecting and handling the samples of No. 4, 5, 6 and 7 coal taken during 1900, 1901, and 1902 was as follows: After an inspection of the mine, a point apparently as nearly representative of the seam as could be obtained was selected for sampling.

The sample was obtained by making a cut across the coal from roof to floor including all the benches of the coal mined and all partings less than three-eighths inch in thickness, but rejecting such impurities as were removed in ordinary work. The cut was from six to eight inches wide by three to four inches deep, care being taken to keep width and depth as nearly uniform as possible. The coal obtained, amounting to from fifty to one hundred and fifty pounds was caught upon a canvas seven feet by seven feet spread upon the floor. This entire sample was transferred to a canvas bag and shipped to the laboratory by freight. Shipped in this way the sample arrived at the laboratory in a partially air-dried condition.

Previous to taking the sample all loose pieces of coal or slate in the seam or roof adjacent to the point to be sampled were dislodged and the section to be sampled straightened up as nearly as possible to a vertical face of fresh coal. In cases where the coal had been exposed for any considerable time the outer exposed portion was removed to a depth of one or two inches before sampling.

The particular conditions under which the sample was taken, the portions of the seam included and the portions rejected in sampling and the analytical results obtained accompanied by the cut of the section of the seam where sampled are given for each sample in that portion of the report prepared by Dr. Bownocker and Professor Orton.

Handling of the Sample in the Laboratory. On arrival of the

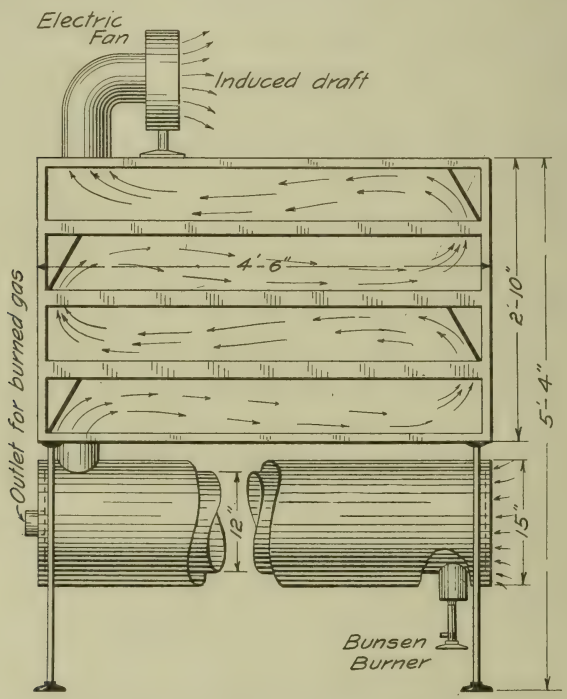
sample at the laboratory it was reduced and quartered by hand and the final portion for analysis ground down on a bucking board till it all passed a sixty-mesh sieve. The analytical work was all done on this partially air-dried sample and the results for moisture on the samples taken in the years 1900, 1901, and 1902 are in all cases lower than the moisture in the coal as mined, and the calorimeter results are likewise higher by an amount proportional to this lower moisture content (in these coals about two or four per cent.), but the results as given are all comparable and probably approximate the moisture content of the coal as marketed under favorable weather conditions.

Method of Sampling Used in Collecting Samples Taken in 1907 of Nos. 8, 8a, and 9 Coal and also a few Samples of No. 5 and No. 6 Coal. The method of collecting these samples is in general similar to the method already described with the exception that the entire sample taken was put through a one-inch mesh sieve and quartered down in the mine and a portion (about 25 pounds) put into a metal can securely sealed and sent to the laboratory by express. Owing to the time and labor involved in quartering down by hand and the difficulty of thorough mixing many of the later samples taken were cut in smaller section (three to four inches by one and one-half to two inches) and the entire sample taken put into the can and shipped to the laboratory. Shipment of the samples to the laboratory in sealed cans prevents moisture loss, and the sample as received represents closely the sample as taken at the mine.

The method of handling the sample in the laboratory is as follows: The 25-pound sample is put through a power jaw crusher and crushed to one-fourth inch. It is then divided by means of a riffle sampler or quartered down by hand to about six pounds, and this six-pound portion spread upon a weighed metal tray 24 by 24 inches and given a preliminary air drying, the loss in weight being recorded as a part of the analytical work done upon the sample. This air-drying treatment is primarily to get the sample into a more constant condition for handling in the laboratory, but it is also of general interest in that it shows the possible loss which may occur during shipment of the coal.

Allowing the coal to arrive at an approximately air-dried condition by simple exposure to the air of the laboratory is a slow process and to expedite the work use is made in the laboratory of a special air dryer in which the trays containing the coal are placed. (P. 312). The air in this dryer is warmed 10 to 15 degrees Centigrade, above the room temperature and kept in constant circulation by means of an electric fan mounted on top of the dryer. In this warmer air the samples rapidly lose their loosely held moisture and at the end of six or eight hours drying at this increased temperature the loss between successive weighings made with an interval of from two to three hours drying usually amounts to less than two or three-tenths of one per cent., and the sample at the end of this time has reached about the same condition as would be attained by drying at atmospheric temperature for three or four days.

This air-dried sample, still further reduced to one-eighth inch by passing through a pair of crushing rolls, is then quartered down till a portion of this product amounting to about three-fourths of a pound is obtained. This portion is then ground to a powder in a closed ball mill jar using quartz pebbles. The jars used are seven inches in diameter by seven inches high inside. The pebbles used are about one inch in diameter. The grinding is accomplished by the pebbles falling over one another, hence to secure best results the speed of rotation of the jars must not be great enough for centrifugal force to overcome the operation of gravity, in which case the pebbles cling to the circumference of the



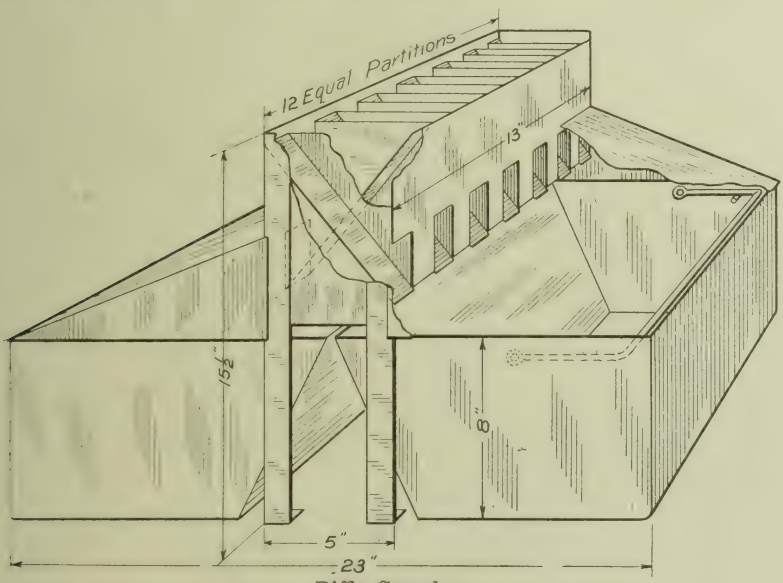
Oven for Air-Drying Coarse Samples..

jar and little or no grinding is effected. In this size jar a speed of from 55 to 60 revolutions a minute gives good results, a three-fourth pound sample being reduced from one-eighth inch to one-sixtieth inch in from 30 to 35 minutes. At the end of the grinding operation the jar is opened and the sample is separated from the pebbles by pouring the contents of the jar upon a coarse sieve.

The fine sample of coal is divided down to about two ounces by passing through a small riffle sampler or the sample is thoroughly mixed by hand with a spatula and about two ounces taken with a sampling spoon from various parts of the material. This two-ounce portion is then put through the 60-mesh sieve, kept well covered during the sifting to prevent moisture changes. A light flat brass ring (about two inches in diameter

and weighing about four ounces) placed in the sieve, is of very great assistance in sifting the sample, preventing caking of the material and clogging of the meshes of the sieve. Usually a few coarse particles, amounting to from one-fourth to one-half per cent. of the sample, remain upon the sieve. These are bucked down by hand on a bucking board and thoroughly mixed with the sifted portion of the sample. The whole is then put in a glass bottle and securely stoppered and constitutes the laboratory sample for analysis.

The jars and pebbles after being cleaned by brushing with a stiff brush, (this part of the operation requiring only a minute or so) are ready for the grinding of another sample of coal. When samples of entirely different material are ground, the jars and pebbles may require more thorough cleansing with water and scrub brush, but, as a rule, in their use for coal, dry cleansing is sufficient.



Riffle Sampler.

The riffle sampler used in reducing the sample is shown in the above figure. Two sizes of sampler are used in the laboratory. The larger size has one-inch subdivisions and is used in reducing the sample from 25 pounds down to the amount to be ground in the ball mill (about three-fourths pound). The sample after grinding in the ball mill is then divided down to about two ounces by means of the smaller sampler having one-half inch subdivisions.

The sampler is essentially a metal box mounted on legs and fitted with a number of equi-distant vertical parallel partitions, the alternate bottoms of the spaces between the partitions sloping in opposite directions. The angle of slope should be about sixty degrees from the horizontal. If much less than this the coal will not run freely and may clog up the sampler.

The lower portions of the sides of the sampler are open and in operation the coal emptied in the top of the sampler runs down the sloping bottoms of the subdivisions and is caught in two buckets below, one-half of the sample being caught in each bucket. To keep down dust the space above the receiving buckets is covered with a metal hood or shield. Three buckets are necessary for convenience in sampling, two to set under the sampler and the third to contain the portion of the sample to be subdivided. After pouring the material through the sampler one of the buckets containing one-half of that poured through is removed and the empty bucket set in its place. The one-half portion is then poured through in turn. The bucket last set under containing one quarter of the original sample is removed and the empty one again set in its place, the subdivision of the sample being continued till the sample is reduced to the amount desired.

After dividing a sample, the sampler is most conveniently cleaned by directing a blast of air from a handbellows through the sub-divisions and any particles of material clinging to the sides or the bottoms of the divisions removed before the apparatus is used for dividing another sample.

METHODS OF ANALYSIS.

The analytical determinations on all of the samples collected during 1901, 1902, and 1903 were made by the writer, who also personally made a considerable number of the determinations upon the samples collected during 1907. Most of the routine analytical work on the 1907 samples was, however, done by Mr. Dana J. Demorest, who by his previous training and experience was well fitted for the work.

The fine samples for analysis are kept in four-ounce wide-mouthed bottles closed with rubber stoppers. Previous to weighing out a portion for an analytical determination the material is thoroughly mixed by giving the bottle fifteen to twenty rotations combined with an upending and tilting movement of the bottle to insure mixing of the top and bottom portions of the sample. For satisfactory mixing in this way the sample should not fill the bottle more than half full. If over two-thirds full the sample should be mixed on paper. After the mixing in the bottle the stopper is removed and the sample still further mixed by means of a sampling spoon and successive small portions then taken till the amount required for the determination is secured, especial care being taken to again securely stopper the bottle before setting aside for other determinations.

Proximate Analysis.

Moisture and Ash. A one-gram portion of the well mixed sample is weighed into an empty capsule and placed for an hour in an oven heated to 105°C. A special double walled oven similar to that used in

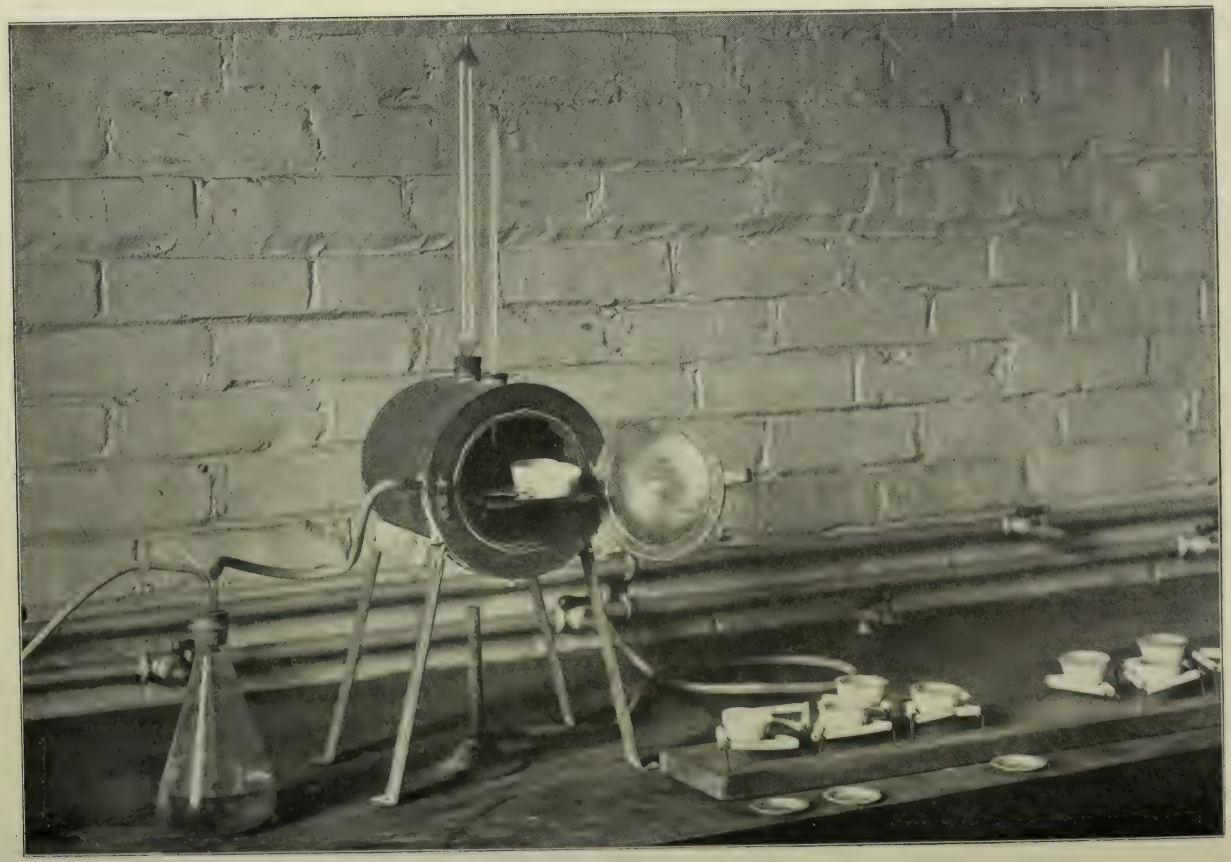


PLATE V. Moisture Oven.

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the Chemical Laboratory of the United States Geological Survey Fuel Testing Plant was used.

A brief description of this oven is as follows: The inner cylinder is four and one-fourth inches in diameter by seven inches long. The movable perforated shelf fitting in this inner cylinder accommodates six capsules. The outer cylinder or wall is six and one-half inches in diameter by eight inches long. The space between the two cylinders is filled to the top of the inner cylinder with a solution of calcium chloride of such strength that the boiling point of the solution is high enough to raise the temperature of the oven to 105°. Concentration of the solution is prevented by means of a reflux condenser fitted into the top of the oven. Air is admitted into the drying chamber through a coil of block tin tubing which passes through the calcium chloride solution. The inner end of the tubing is soldered into the rear wall of the drying chamber and the outer end is connected to a flask containing concentrated sulphuric acid.

During a determination air under pressure is bubbled through this sulphuric acid, passes through the block-tin coil into the drying chamber and escapes through a small orifice in the door of the oven. The air is passed through at such a rate that a volume equal to the capacity of the oven passes through every six or eight minutes. Most of the moisture of the sample is driven off during the first fifteen or twenty minutes so that by the end of the hour the air in the oven is parctically dried by the sulphuric acid. By working in this way variations in the humidity of the laboratory air do not affect the determinations and duplicates run at different times agree much more closely than where an ordinary air oven is used. At the end of the hour the capsules are removed from the oven, covered, and allowed to cool in desiccators over concentrated sulphuric acid and then weighed covered.

Sulphuric acid gives more concordant results than calcium chloride, as experiments show that if allowed to remain over calcium chloride for any considerable time, the sample dried at 105°C. increases in weight and the results for moisture are correspondingly low. The danger of sulphuric acid splashing up on to the bottom of the capsule when the desiccator is being carried around the laboratory is eliminated by placing a thin sheet of asbestos paper below the capsule, taking care to have it fit so loosely in the desiccator as not to prevent free circulation of air.

Special flat aluminum lids are used in connection with the capsules used in the moisture determinations. They are light and unbreakable, and are much more convenient to handle than the heavy breakable covers ordinarily used with porcelain crucibles. In weighing out the sample at the beginning of the determination the lid is placed upon the balance pan under the empty capsule in which the sample is weighed. The capsules used are heavier and less flaring than the ordinary porcelain crucibles. The dimensions are one inch high by one and five-eighths inch

in diameter at the top. They were obtained from the Henry Heil Chemical Company, St. Louis, and are designated as "porcelain moisture capsules No. 2". They are much more satisfactory for this work than ordinary porcelain crucibles.

After the determination for moisture the sample is burned to ash in a muffle, care being taken to begin the burning off at a low heat to avoid coking of the coal, the temperature of the muffle being raised to redness after the expulsion of the volatile matter. Heating is continued till all black carbon is burned out, the capsule is then removed from the muffle furnace and allowed to cool in the open air and weighed as soon as cooled, it is then replaced in the red-hot muffle for from fifteen to thirty minutes, again allowed to cool and reweighed, continuing this process if necessary till constant weight is obtained.

Volatile Matter. The method used is that recommended by the Committee on Coal of the American Chemical Society. A one-gram sample is weighed into a 30 cc. platinum crucible, the closely fitting lid placed upon the crucible and the whole heated for seven minutes over the full flame of the Bunsen burner, the distance of the crucible from the top of the burner and the height of the burner flame being so adjusted that the entire crucible including the lid is heated to a visible redness during the operation. With artificial gas the distance between the top of the burner and the bottom of the crucible is kept about 7 cm., the free burning Bunsen burner flame being 16 to 20 em. in height. With natural gas a more uniform heating of the crucible is obtained if the distance between the top of the burner and the bottom of the crucible is about 12 cm. and the free burning flame about 30 cm. in height. To prevent air currents from interfering with the determination a cylindrical chimney of asbestos about 15 cm. long by 7 cm. in diameter is used to enclose the burner flame, the triangle upon which the crucible rests being located about 3 cm. below the top of the chimney. This arrangement gives a more uniform heat and more concordant results are obtained.

Fixed Carbon. The Fixed Carbon is the difference between 100 and the sum of the moisture, ash and volatile matter.

Sulphur. The Eschka method was used on all samples. To check these, duplicate determinations were made on the washings from the calorimeter determinations. The two methods give very closely agreeing results. The routine of the work by the Eschka method is as follows: One gram of the well-mixed sample is thoroughly mixed in a 30 cc. platinum crucible with about one and one-half gram of the Eschka mixture (two parts light calcined magnesium oxide plus one part anhydrous sodium carbonate) about one-half gram of the mixture is then spread on top as a cover.

The burning out is done over grain or wood alcohol, gasoline gas or natural gas, experiments having shown that the sulphur contained in gasoline gas and natural gas is so small in amount that little or none

of it is taken up by the Eschka mixture. Ordinary artificial gas is so high in sulphur that its use is not permissible, as blanks are likely to be large and variable and consequently the correction to be applied is uncertain. At the beginning the flame is kept low until the volatile matter is burned out. This requires from fifteen to thirty minutes. The heat is then increased and the mixture stirred occasionally with a platinum wire, the heating being continued till all traces of unburned carbon have disappeared.

The mixture in the crucible is then transferred to a 200 cc. beaker and digested with 75 cc. of water for at least 30 minutes. The solution is then filtered and the residue washed twice with hot water by decantation and then washed on the filter, small portions of water being used for each of the washings until the filtrate amounts to 200 cc. Bromine water in excess is then added, and the solution made slightly acid with hydrochloric acid. The amounts of these reagents usually added are 4 cc. of water saturated with bromine and 3 cc. of concentrated hydrochloric acid.

The solution is heated nearly to boiling and the sulphur precipitated with 20 cc. of a hot five per cent. solution of barium chloride, slowly added from a pipette during constant stirring. The solution and precipitate are allowed to stand at a temperature a little below boiling for two hours or longer before filtering. The filtrate from the barium sulphate is tested for acidity by means of litmus paper, and for excess of barium chloride by adding a few drops of dilute sulphuric acid to a few cc. of the filtrate in a test tube. The preliminary washing of the precipitate is done with hot water containing 1 cc. of hydrochloric acid per liter. The final washings are made with hot water alone and the washing is continued until the washings no longer react for chlorine when tested with silver nitrate.

The precipitate is ignited in a porcelain crucible. The filter and precipitate are placed in the crucible, precipitate uppermost, and the filter folded only enough to prevent loss by spattering. A low heat is used until the paper is entirely "smoked off." The heat is then raised sufficiently to bring the precipitate to dull redness, and the heating continued for a few minutes, or until the carbon is burned out. The crucible and precipitate are then cooled and weighed. The weight of barium sulphate less the blank from the reagents, multiplied by .137 equals the amount of sulphur in the sample.

Ultimate Analysis.

The ultimate analyses were made in regular 25-burner combustion furnaces. Our experience is that the accuracy of the results obtained are largely dependent upon the manipulation and skill of the chemist making the determination, and details and description of the method of

work are not out of the way here, although the process itself is so well known.

The purifying train through which the air and oxygen are passed before they enter the combustion tube are arranged in duplicate, one part for air, the other for oxygen. The purifying reagents, arranged in the order named, are sulphuric acid, potassium hydroxide, soda lime and granular calcium chloride. The combustion tubes are about forty inches long and about five-eighths inch internal diameter. The tube extends beyond each end of the furnace for a distance of about four inches, the ends of the tube being protected from the heat of the furnace by closely fitting circular shields of asbestos. The rear end of the tube (the end next to the purifying train) is closed with a rubber stopper. This end of the tube being kept cool by the protection of the circular shield and by the passage of cool air and oxygen, there is very little danger of volatile products being given off by the rubber. The other end of the tube is closed by a well-rolled cork of specially selected quality, the danger from overheating at this end of the tube being too great to permit of the use of the more convenient rubber stopper.

The rear end of the tube for a distance of ten inches inside the furnace is left empty; the next fourteen inches is filled with a loose layer of wire copper oxide, with a plug of acid-washed and ignited asbestos at either end to hold the oxide in place. The copper oxide is followed by a layer about four inches in length of coarse fused lead chromate, to stop sulphur products, this being held in place by a final plug of asbestos.

The absorption train is as follows: The water is absorbed in a six-inch U tube, filled with granular calcium chloride; the carbon dioxide is absorbed by potassium hydroxide in an ordinary Liebig bulb, to which is attached a three-inch U tube containing soda lime and calcium chloride, the bulb and U tube being weighed up together. This is followed by a final guard tube filled with calcium chloride and soda lime. The gases formed during combustion are drawn through the train by suction, a Marriott bottle being used to secure a constant suction head.

The oxygen used is kept over water and is supplied under small pressure. The supply of oxygen and the aspiration during a combustion are so regulated as to keep the difference in pressure between the inside and outside of the tube very small, the pressure inward being slightly greater. This reduces the danger of leaks to a minimum, and, if by chance any slight leakage does occur, it is inward rather than outward and the effect upon the determination is small.

Before beginning the determination the apparatus is tested for leaks by starting the aspirator and shutting off the supply of air. With the aspirator on full if not more than four or five bubbles of air per minute pass through the potash bulb, the connections are sufficiently tight to proceed with the determination. Air is then admitted to the purifying apparatus, the tube heated to redness throughout and 1000 cc. or more

of air aspirated. The potash bulb and drying tube are then detached and weighed. They are again connected up and 500 cc. of oxygen followed by 1000 cc. of air aspirated through the train.

On commencing the second aspiration the burners under the rear portion of the tube are gradually turned down and finally entirely out. so that the empty portion of the tube into which the sample for analysis is to be inserted becomes nearly or quite cool, by the time the aspiration is complete. The burners under the two-thirds of the copper oxide next to the lead chromate are kept lighted and this portion of the oxide kept at a red heat. After aspiration of the 1000 cc. of air, the potash bulb and drying tube are detached and again reweighed. If the gain or loss in weight is less than .5 mg. the apparatus is ready for an analysis.

The absorption apparatus is then again connected up and two-tenths gram of the well-mixed sample weighed into a platinum boat and the boat and sample pushed into place in the combustion tube as quickly as possible and slow aspiration of the train started at the rate of one or two bubbles a second through the potash bulbs and a mixture, in the proportion of about two bubbles of oxygen to one of air, admitted into the train through the purifying apparatus. The burners under the remaining copper oxide and behind the boat are lighted and the moisture and volatile matter gradually driven off.

This part of the operation requires very careful watching and manipulation to secure correct results. The copper oxide must be at a good red heat or the combustion of the hydrocarbons is very liable to be incomplete. If the evolution of the hydrocarbons is too rapid incomplete combustion or absorption also results. Also if the evolution is too rapid back pressure is developed in the train and losses are almost sure to occur either from moisture getting back into the tube of the purifying apparatus or from slight leaks in the train. When the volatile matter is expelled that portion of the tube containing the boat is heated to redness, more oxygen is admitted into the train and the fixed carbon gradually burned off, using care not to allow the combustion to take place too rapidly or fusion of the ash and incomplete combustion may result.

Oxygen is admitted for about two minutes after the fixed carbon is burned out, which may be seen by the sudden disappearance of the glow. The oxygen is then turned off and air aspirated through the train, the burners under the rear portions of the tube being gradually turned down and out. After 1000 cc. have been aspirated the absorption apparatus is detached and weighed. One-ninth the increase in the weight of the drying tube equals the hydrogen and three-elevenths of the increase in the weight of the potash bulb equals the carbon from the sample. The absorption apparatus is again connected up, the platinum boat removed from the tube. the ash carefully examined for complete combustion and another two-tenths gram sample of coal weighed out for another determination.

Nitrogen. This determination was made by the regular Kjeldahl method, using concentrated sulphuric acid with metallic mercury. This process is too well known to need any particular description here other than mention of the fact that long digestion is necessary to secure complete oxidation. The digestion should be continued for at least three-fourths of an hour after the oxidation is apparently complete. In a bituminous coal if the sample be finely ground the total time for digestion is about three hours.

Calorimeter Determinations.

The calorimeter determinations were all made in the Mahler calorimeter. This calorimeter, the most widely used of the oxygen type, is now well known. A brief description of its construction and details of its operation and the method of calculating results are as follows: Plate VI. shows the important portions of the apparatus. The steel cylindrical bomb in which the combustion takes place has a capacity of about 600 cc. It is fitted with a removable lid to which the platinum tray upon which the sample is placed is attached. Connected to the lid are two platinum rods leading to the tray and to one of which it is attached, these rods being insulated from one another in the lid.

The ignition of the sample is secured by the burning of a small spiral of iron wire (weighing about 13 mg.) attached to the two platinum rods and bent down till it is nearly or quite in contact with the coal. After the sample and ignition wire are in place, the lid is screwed on the bomb and securely tightened, leakage being prevented by means of a lead gasket between the top of the bomb and the lid. Oxygen under pressure (supplied to the trade in steel cylinders at about 100 atmospheres pressure) is now admitted into the bomb through the valve stem, 18 to 20 atmospheres being used. The lower portion of the stem is fitted with a needle valve, which, after the proper amount of oxygen has been admitted, is closed by giving the bomb about one-half turn, very little force being required to close it if the valve is in working order.

After filling the bomb with oxygen, 2400 grams of water are poured into the brass bucket, which is then placed inside the insulated jacket. The bomb is then placed inside the brass bucket containing the 2400 grams of water and the stirrer for agitating the water during combustion fitted into the place. Wires for completing the electric circuit through the platinum rods and ignition wire inside the bomb are attached to terminals on the lid of the bomb.

The thermometer for recording temperature increase is clamped into place and so adjusted that the lower end of the mercury bulb is about two inches above the bottom of the bucket. The thermometer is graduated to one-fiftieth degree Centigrade and is read through a reading telescope set up about five feet distant. For convenience of operation this telescope is fitted to a sliding cathetometer. By the use of this cathetometer the rise of the mercury column during combustion is easily followed through the telescope.

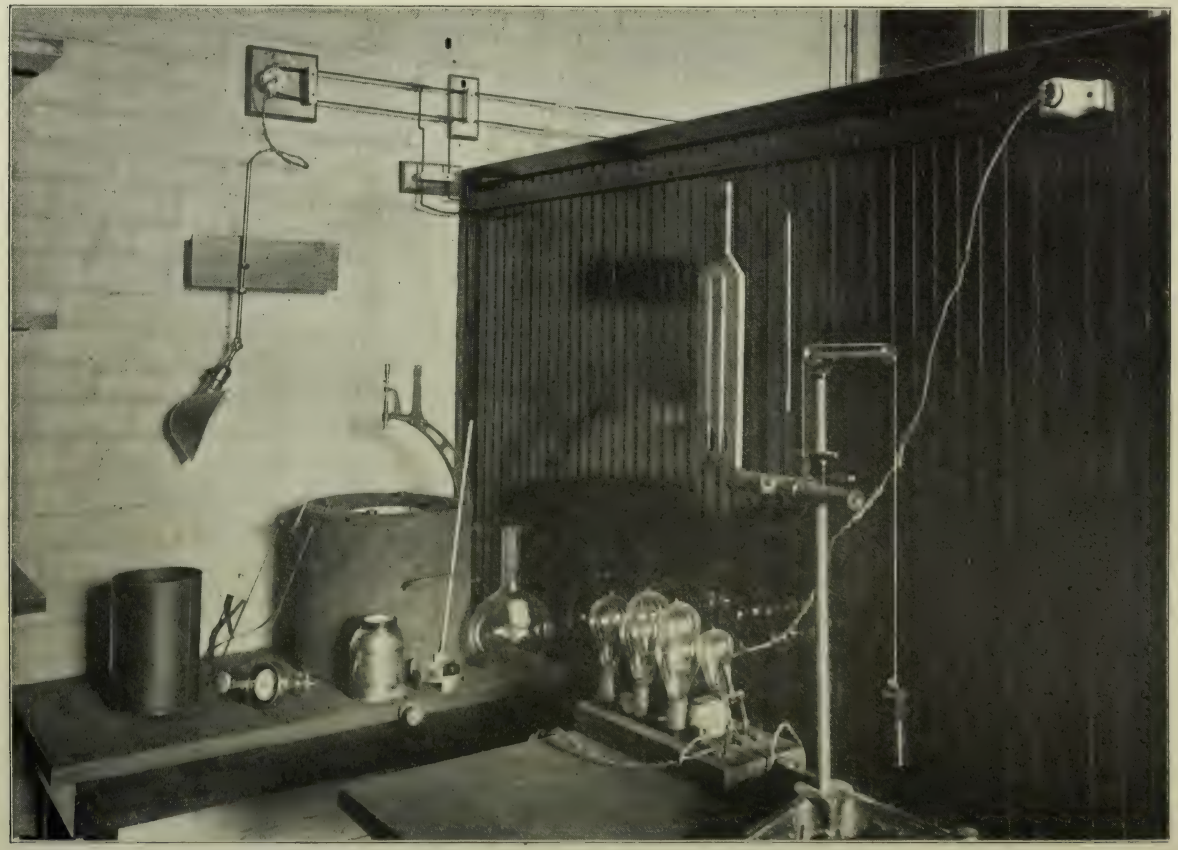

Plate VI. Mahler Calorimeter with Reading Telescope and Lamp Bank Resistance.

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After all attachments have been properly made, the water in the bomb is kept in circulation by means of the stirring apparatus and minute readings of the thermometer taken till a definite regular rate of gain is established. The electric circuit is then completed by closing a switch and the combustion takes place. This is followed by a very rapid increase of temperature for several minutes, after which the change in the system becomes small. The minute readings are continued till this rate of change is also established.

The observed increase of temperature together with the rates of gain or loss at the beginning and end of the operation in connection with the water equivalent of the apparatus and water used furnish all the data for calculating the calories of heat developed during the combustion. This calculation may possibly best be shown by a typical determination giving the results obtained.

GEOLOGICAL SURVEY OF OHIO.

Sample No. 516. Date, 11/4/07

Wet and dry bulbs = 12-22 °C.
Jacket Water = 21 °C. Coal = 1.0018 gms.

Time.	Readings:				
7–50	19.318				21.744°
51	19.326				19.348°
52	19.334	+.0075 rate of change.			
53	19.340			Observed temperature change =	2.396°
54	19.348	+.0075		Radiation loss =	.0093
		+.0026			
½	20.2	+.0030		Corrected temperature change =	2.4053
		+.0001		Water Equivalent 1° =	2875.
55	21.40	—.0025			
		—.0034			5750.0
56	21.700	—.0043			1150.0
		—.0043			00.0
57	21.746	—.0043			14.4
		—.0043			.9
58	21.744	—.0043			
59	21.740	—.0093		Calories of heat developed =	6915.3
60	21.736			Corrections =	100.1
1	21.734	—.0043 rate of change.			
2	21.728			Heat from sample =	6815.2
3	21.722			Correction for excess sample	
4	21.718			over 1 gram =	12.2
				Calorific value of coal =	6803.0

Wire fuse = 10 cm. = 13 mg.
Wire fuse, unburned = 2 cm.
Wire fuse, burned = 8 cm. = 10.4 mg. (1 mg. = 1.7 cal.) = 17.7 cal.
Titer 23.8 to 31.6 = 7.8 cc. (1 cc. = 5 cal.) = 39.0 cal.
Sulphur in coal 3.34% (.01 gm. = 13 cal.) = 43.4 cal.
TOTAL CORRECTION = 100.1 cal.
Thermometer used, No. University 25°. Position 5 cm.
Room temp. = 22°
Atm. oxy. used = 18 Valve, light.
At 19° added 4.5 cc. of water to obtain 2400 grams.

(Signed) E. E. S.

Checked by E. S. D.

The complete record includes the following points: Room temperature, wet and dry bulb readings, temperature of the water in the outer jacket of the calorimeter; pressure in atmospheres of the oxygen in the bomb; condition of the valve of the bomb, thermometer used and its position in the calorimeter during a determination, that is, the distance of the lower end of the bulb above the bottom of the calorimeter bucket, two inches being taken as the standard distance. In beginning a determination minute readings are taken until a regular rate of change has been established. This usually requires only five or six readings, but occasionally seven or eight. When the initial rate is established the combustion is begun at the time of the next minute reading by closing the switch completing the electric current. During the first minute after ignition half-minute readings are taken, after which minute readings are taken until a final rate of change has been established. This usually requires about six readings, but occasionally as many as ten are taken.

The temperture taken for the beginning of the combustion is the reading taken at the time of the burning of the wire fuse. For the end of the combustion period the first temperature reading is taken, which falls well within the established final rate. Some chemists adopt an arbitrary time of five minutes as the combustion period, but in our opinion better and more concordant results are obtained if allowance is made for variations incident to the determination by selecting for the end of the combustion period a temperature which falls in line with the final series of readings.

The corrections applied to the combustion period are obtained by taking into consideration that the changes in the rate of gain or loss in temperature are proportional to the changes in temperature. From this proportion the rate of gain or loss at the beginning and end of each interval of time is found.

In the typical determination given the current was turned on and the combustion started at the beginning of the 54th minute. The increase in temperature during the four minutes preceding is 19.348—19.318=.030° or .0075° per minute. After the beginning of the combustion the temperature increases rapidly, reaching a maximum at the 58th minute, after which there is a rather regular fall during the next seven minutes. Inspection shows the rate of loss to be about .0040° per minute. The reading at the 58th minute is the first reading which falls in line with this rate of change and is therefore taken as the reading for the end of the combustion period.

The observed temperature increase is the difference between the temperature at the beginning and end of the combustion period, 21.744—19.348=2.396°. The loss during the six minutes following the combustion period is 21.744—21.718=.026 or .0043° per minute. The total change in the rate of gain or loss in the system corresponding to 2.39° increase in temperature is a change from a rate of +.0075 to a rate of--

.0043 or a total change of .0118°. A change in rate of .0118° with a change in temperature of 2.39 is equivalent to a change in rate of approximately .0005° for each .1° temperature change, from which the rate of gain or loss at the differnt readings can be obtained. At 54½ minutes the temperature change is (counting to the nearest tenth degree) nine-tenths of a degree equal to a change in rate of nine times .0005=.0045 As the total change was from a plus to a minus rate, this amount will have to be subtracted from the plus rate at the 54th minute. +.0075—.0045 =.0030. At the 55th minute the change is 2° equivalent to a rate change of .010. +.0075—.010=—.0025. The temperature at the 56th and 57th minute being practically the same as that of the 58th minute, the rate of change is the same—.0043.

The actual temperature gain or loss for each of the different intervals is found by adding the rates at the beginning and end of the interval and dividing by two if a minute interval or by four if a half-minute interval. The sum of the rates at the beginning and end of the interval from 54 to 54½ is +.0075+(+.0030)=+.0105. This divided by 4 gives .0026°, the temperature gain during the interval. For the interval 54½ to 55, +.0030+ (—.0025)=.0005. This divided by 4 =+.0001. For the minute interval 55 to 56,—.0025+(—.0043) =—.0068. This divided by 2=—.0034. The losses in the other intervals are obtained in a like manner. Adding together the different gains and losses, the total loss is found to be .0093. The correct temperature change is therefore the observed temperature change increased by this amount 2.396+.0093=2.4053°, the actual temperature change. The water equivalent of the system is 2875 calories. Multiplying the temperature change by this water equivalent (i.e. by the number of calories necessary to cause a rise of 1° of temperature), the total heat developed during combustion is found to be 2.4053x2875=6915.3.

Corrections. The heat from the burning of the wire fuse is found by multiplying the weight of wire taken by its calorific value (1.7 calories for 1 mg.) 10.4 mg. x 1.7=17.7 calories. The acidity of the bomb liquor after combustion is found by titrating it with a standard ammonia of such strength (.0057 grams of ammonia per cc. See acidity corrections) that one cc. corresponds to a heat correction of five calories, assuming the acidity to be entirely due to nitric acid, from which 7.8 times 5 equals 39 calories, the correction due to the formation of nitric acid.

A large part of the acidity in high sulphur coal is, however, due to sulphuric acid, and the heat correction for acid formed, considering it all as nitric acid, is therefore incomplete, a further correction of 13 calories for each .01 gram of sulphur present being required. (See acidity corrections). 3.34 per cent. sulphur in the sample is .0334 grams sulphur on one gram sample taken. Therefore, the correction is 3.34x 13=43 calories.

The total of these corrections is 100.1 calories. 6915.3, the total

heat developed, less this correction of 100.1 gives 6815.2 calories of heat from the combustion of the coal. These 6815.2 calories are developed by 1.0018 grams of sample. The value per gram is therefore 6815.2 divided by 1.0018. The amount of sample taken is so near one gram that this correction can be approximated as .68 of a calorie for .0001 gram of coal. For .0018 the correction is accordingly 18 times .68=12.2. Making this correction gives 6803. as the calorific value of the coal.

SPECIAL NOTES.

Sample for Combustion. In obtaining the sample about two grams are pressed into a small briquette by means of a small screw press and mold (Plate VII.). The press used in connection with this calorimeter work is the iron frame of a two-quart tincture press manufactured by the Enterprise Manufacturing Company, Philadelphia, Pa. In compressing the briquette only sufficient pressure is used to insure the sample holding together, as if the briquettes are pressed too much there is more liability of incomplete combustion. After removal from the mold the briquette is broken into smaller portions and about one gram accurately weighed and put into the platinum tray already mentioned. The pressing of the coal into briquettes prevents loss of fine coal during the filling of the bomb with oxygen, while the breaking of the briquette into smaller pieces has been shown by experience to lessen the liability of incomplete combustion from unburned particles flying out of the tray.

Anthracite coals and cokes cannot be briquetted and are best run by placing a small disc of ignited asbestos upon a platinum tray and then weighing the anthracite or coke directly upon this disc, taking especial care in filling the bomb with oxygen to admit it very gradually in order to prevent particles blowing off of the tray. Efforts to burn coke and anthracite directly upon the platinum tray frequently give low results, possibly explained by the slow burning of the coke and anthracite samples and the rapid conduction of heat by the platinum. The disc by lessening this conduction loss aids in securing completeness of combustion, and higher and more concordant results are obtained by its use.

Preventing Leakage of Valve. By use the valve through which the oxygen is admitted into the calorimeter soon becomes corroded from the action of the acid fumes and rusted through the action of moisture and air. In this condition it is extremely difficult to prevent considerable leakage of oxygen. This leakage may be prevented and the valve made to fit tight by cutting a thin washer of lead about one-thirty-second inch in thickness and fitting into the valve using care in its insertion not to get it in crosswise and thereby close the opening into the bomb. A very efficient way to insert it is as follows: Hold the valve stem, valve-end up and slip the washer over the tip of the needle. Then with the stem in this vertical position screw the lid on to the stem carefully till the washer is pressed into place. Very slight pressure is required to close

PLATE VII. Briquette Press and Equipment for Filling Calorimeter Bomb with Oxygen.

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the valve when fitted in this way and extra pressure is to be avoided as tending to force lead into the needle opening, which may be entirely closed and will in this event require drilling out before the bomb can be used again.

Water Surrounding the Bomb. In the regular routine determinations the amount of water used is measured, not weighed. For this purpose a larger Erlenmeyer or Florence flask holding about 2400cc. of water when filled to the middle of the neck is used. The number of grams of water that it delivers is determined by filling it to a fixed mark and weighing at a definite observed temperature. The flask is then emptied and allowed to drain 15 seconds and again reweighed, an allowance of 2.4 grams being made for the effect of the buoyancy of the air displaced by this amount of water. The difference in weight is the number of grams of water the flask delivers at this temperature. A table is then prepared giving for different temperatures the number of cc. of water which must be added to the water inside of the flask to obtain 2400 grams.

The diameter of the neck of the flasks used is from one and one-fourth to one and three-eighths inches. With this size of neck and a uniform time of fifteen seconds for drainage, the amount of water can be measured to an accuracy of 1 cc. or less and errors of measurement do not affect the calorific value obtained over two or three calories. The time required for measuring is less than that required for weighing and does not involve the continued use of an expensive balance and set of weights.

Temperature Conditions. More satisfactory rates of gain or loss during a determination are secured if the temperature differences between the air of the laboratory and that of the water inside the inner bucket and in the outer insulating jacket are kept small. In the laboratory the practice is to keep the temperature of the water in the outer jacket within a few degrees of room temperature. The water to be used in the inner bucket is cooled till its temperature is about two to three degrees lower than that of the water in the outer jacket, care being taken that this temperature is not too near the dew-point. In damp weather to avoid this danger, the water in the outer jacket is kept several degrees above room temperature.

With these temperature relations the greater rate of change during a determination is before the combustion, and the rate of change after the combustion period is small. The larger the rate of change the larger is the possible error. The effects of the larger rate before the combustion period are after the first minute practically eliminated, as by the end of the first minute most of the total temperature rise has occurred and the rate change during the other minutes of the combustion period approximates in value the final rate. With the final rate small the total corrections are correspondingly small and errors from this source are reduced to a minimum.

Acidity Corrections. Data for the correction for formation of nitric and sulphuric acids are as follows: The heat of the formation of aqueous nitric acid is 1058 calories per gram of nitrogen. The heat of the formation of aqueous sulphuric acid is 4450 calories per gram of sulphur. In ordinary combustion of the coal the sulphur is burned to sulphur dioxide, the heat of formation of which is 2250 calories per gram of sulphur. The excess heat due to the formation of sulphuric acid in the bomb is therefore 4450—2250=2200 calories per gram of sulphur.

In neutralization, the reactions are $2HNO_3+NH_4OH=2NH_4NO_3+H_2O$ and $H_2SO_4+2NH_4OH=2(NH_4)_2SO_4+2H_2O$. The strength of the solution of ammonia, such that one cc. equals five calories, based on the heat of formation of nitric acid, is calculated as follows: 1058 calories equals the heat of formation of one gram of nitrogen to aqueous nitric acid, from which five calories equal .00473 grams nitrogen to aqueous nitric acid. One atom of nitrogen as nitric acid neutralizes one molecule of ammonia. Expressed in terms of ammonia, 14:17::.00475:X. X equals .00574 grams ammonia per cc. The relation between sulphuric acid and ammonia is one of sulphuric acid to two of ammonia. One cc. of ammonia solution equals .00574 grams NH_3. Its equivalent strength in sulphur as sulphuric acid is therefore 34:32::.00574:X. X equals .0054 grams sulphur as sulphuric acid. The heat correction for one gram of sulphur is 2200 calories. The correction for .0054 grams is 2200 times .0054, equals 11.9 calories.

It is evident that after multiplying the number of cc. used in the titration by the factor for nitric acid (five calories), it is necessary to make a further correction of 11.9 minus 5 equals 6.9 calories for each cc of ammonia used in titrating sulphuric acid instead of nitric. Since one cc. equals .0054 grams sulphur as sulphuric acid, this corresponds to a correction, for each one-hundredth gram of sulphur, of 6.9 divided by .54=13 calories. The total correction for acidity is obtained therefore by multiplying the cc. of ammonia required by 5 (the factor for nitric acid) and adding 13 calories correction for each one-hundredth gram of sulphur present in the sample.

Ignition of Iron Wire. For igniting the wire fuse used for starting the combustion of the coal a current with an electro-motive force of 15 to 20 volts is desirable. The ignition may be made with lower voltage using the current from a four-cell chromic acid or storage battery or from four or five dry cells in series, but with low voltage, unless special care be taken in wrapping the wire to the platinum terminal rods, failure to ignite often results. If a current of low voltage is used, better contact between the platinum terminals and the iron wire is secured if the rods and wire are carefully cleaned with emery paper and the wrappings of the iron wire around the platinum terminals moistened with a drop of calcium chloride solution. Working in this way, failures of the wire to ignite are reduced to a minimum.

The use of a current of high voltage, as that from a 110 volt lighting circuit, is liable to result in errors, due to heat produced by leakage of current after the ignition of the iron wire. Where current of this high voltage is used, the possible error introduced by using it direct may be eliminated by using a resistance coil connected in parallel with the calorimeter and shunting only a portion of the current through the ignition wire.

In igniting the wire, sufficient current should be used to fuse it in a fraction of a second, as, if the wire is slow in burning, an appreciable amount of heat is radiated from the wire before it finally fuses. The wire ordinarily used with the Mahler calorimeter is about .12 mm. in diameter, ten centimeters weighing about 13 mg. With this size of wire a current of not less than three amperes is desirable.

In the laboratory using the current from a 110-volt lighting circut satisfactory results, as to current and voltage, are obtained by putting as a resistance into the circuit a group of four parallel lamps (32-candle-power) in series with a coil of German silver wire of about five ohms resistance and connecting the wires leading to the calorimeter to the ends of this German silver coil. (Page 329). By this arrangement the difference of potential across the calorimeter after the ignition of the wire is only about 20 volts and the leakage of current is reduced to a negligible amount. With the connection arranged in this way failures of the iron wire to ignite are also very unusual.

In the regular routine of making a determination, the time interval during which there is a possibility of leakage of current is about two seconds, as in burning the wire the switch is kept closed for that length of time. With the arrangement as described frequent tests for leakage were made after completion of a determination by again closing the switch for thirty seconds and taking several additional minute readings of the thermometer. These additional thermometer readings in every case showed little or no variation to have been produced in the rate of temperature change. Similar tests for leakage using the same lamp bank resistance but omitting the German silver coil showed with the switch closed for thirty seconds a leakage of current through the calorimeter sufficiently large in amount in some instances to produce a heating effect of several hundred calories. The insulation of the calorimeter used was afterwards found to be defective and the greater part of the heating effects observed are probably to be attributed to this cause.

The iron ignition wire used (twelve-hundredths of a millimeter in diameter and about two centimeters between the terminals) if in good contact with the platinum terminals has a resistance of less than one ohm and the amount of heat developed during the fraction of a second that current passes through the wire before it ignites is small. The resistance of the calorimeter itself with the insulation in good condition is several millions of ohms. A test on one of the calorimeters indicates a resistance

of upwards of twenty million ohms, the test being made on a 120-volt circuit. Pure water is such a poor conductor that after immersion of the calorimeter in water the resistance is still high (expressed in thousands of ohms).

In routine work the distilled water used to surround the calorimeter bomb is used over and over again. The resistance of this water, owing to traces of impurities, is not so great as that of the original distilled water, but its resistance is still high. Tests usng water which had previouly been used in making forty or fifty calorimeter determinations show with a 120 volt circuit about 1500 ohms resistance. Tests using distilled water taken directly from the laboratory supply showed a resistance of about 5,000 ohms. With the resistance in excess of one thousand ohms, the heating effect due to leakage of current is quite small and the danger from excessive leakage is either from defective insulation of the bomb itself or from the use of water containing more than traces of impurities. The possible heating effects under these conditions are discussed in the next paragraph.

Heat Developed While the Circuit is Closed for Ignition of the Iron Wire. The heat developed in a conductor of which the resistance is R ohms by current of I amperes in a time of t seconds is $0.2387\ RI^2t$ calories.

Using the current from a 110-volt circuit with four candle-power lamps in parallel, the greatest current is approximately four amperes. With the German silver resistance coil (five ohms resistance) in the circuit, the possible heat developed by passage of current through the calorimeter is small. Before the ignition of the iron wire with a low resistance in the calorimeter circuit (a fracton of an ohm) practically all the current passes through the calorimeter, but since I cannot exceed 4, I^2 cannot exceed 16, and with the resistance less than one ohm, the product of .2387 RI^2 is less than four calories per second.

After the ignition of the iron wire under normal conditions the resistance of the calorimeter circuit is expressed in thousands of ohms and practically all the current passes through the German silver coil having only five ohms resistance. Take as a special case the 1500 ohms resistance found in test. With this resistance such a small portion of the current flows through the calorimeter that its heating effect is less than one tenth calorie per second. With defective insulation in the calorimeter or with very impure water, the resistance may be very much less than this and the possible effects under these conditions should be considered.

Take as special cases resistance of ten ohms and one hundred ohms in the calorimeter. With the circuit closed the total current flowing through the resistance coil and the calorimeter is approximately four amperes. This varies slightly on account of small changes in the total resistance of the circuit due to the variations in the calorimeter resistance, but this variation in current is so small that it may be neglected in discussing the heat effect in the calorimeter. With the calorimeter and coil connected in parallel, the portion of the total current passing through

each is inversely as its resistance is to the sum of the two resistances. With ten ohms resistance in the calorimeter and five ohms resistance in the coil the portion of current passing through the calorimeter is

$$\frac{5}{10+5} = \tfrac{1}{3}. \quad \tfrac{1}{3} \text{ of } 4 = 1.3 \text{ amperes.}$$

With 100 ohms resistance in the calorimeter the portion of current passing through it is:

$$\frac{5}{100+5} = \tfrac{1}{21}. \quad \tfrac{1}{21} \text{ of } 4 = .2 \text{ amperes.}$$

Applying the formula for heat production with ten ohms resistance $.2387 \times 10 \times (1.3)^2 = 4$ calories per second. With 100 ohms resistance $.2387 \times 100 \times (.2)^2 =$ one calorie per second.

With resistance between one and ten ohms, the heating effects are very close to four calories. With a resistance of over ten ohms the heating effects are less than four calories per second, from which it appears that using the resistance coil in circuit under no condition can the leakage of current per second be large enough to very appreciably affect the results obtained on the calorific value of the materials tested.

Resistance Coil Left Out of the Circuit. Before the burning of the iron wire with little resistance in the calorimeter (less than one ohm, approximately four amperes of current will pass through the calorimeter and the heating effect is small (less than four calories per second.) After the burning of the iron wire under normal conditions with the resistance expressed in thousands of ohms, the heating effect due to current passing through the calorimeter is also small. In the special test upon the calorimeter showing 1500 ohms resistance, the heating effect of the current flowing through the circuit is between two and three calories per second.

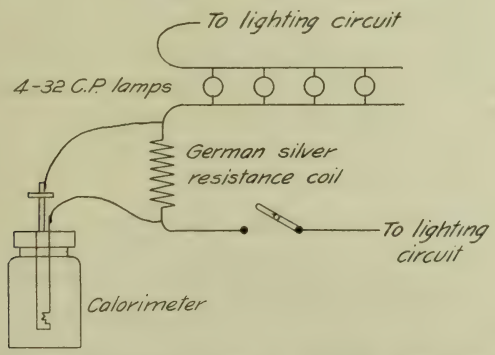

Diagram of Circuit Used in Igniting Wire Fuse.

With the lower resistances, which may occur, due to defects in the insulation or the use of very impure water, the effect may be of considerable magnitude and the possible effects with resistance between one and 1500 ohms should be considered. Small increases in the resistance in the calorimeter diminish the amount of current flowing only slightly and

the amount of heat produced increases very nearly in proportion to the increase in resistance.

With one, two and three ohms resistance in the calorimeter, the heat produced is approximately 4, 8 and 12 calories per second. With larger increases in resistance the change in current due to the change in the total resistance of the circuit should be considered. The total resistance of the circuit is the resistance of the lamps 1/4 (110 ohms) plus the resistance in the calorimeter plus the resistance in the rest of the current. The resistance of the rest of the circuit is small and the total resistance outside the calorimeter is accordingly approximately that of the lamps, 1/4 (110 ohms). The total resistance of the circuit is approximately 27 ohms plus the resistance of the calorimeter.

Ohms law for current flowing through a conductor is $I=\frac{E}{R}$. Considering as special cases the effect of 10, 100 and 1000 ohms resistance in the calorimeter:

(a) With 10 ohms resistance the current is $\frac{110}{27+10}=3$ amperes.

(b) With 100 ohms resistance the current is $\frac{110}{27+100}=.9$ amperes.

(c) With 1000 ohms resistance the current is $\frac{110}{27+1000}=.1$ ampere.

Applying the formula for heat developed in the calorimeter:

(a) $.2387 \times 10 \times (3)^2=21$ calories per second.

(b) $.2387 \times 100 \times (.9)^2=19$ calories per second.

(c) $.2387 \times 1000 \times (.1)^2=3$ calories per second.

With normal conditions, good insulation in the calorimeter and water practically free from impurities, the effects of leakage of current are unimportant, but with defective insulation or water high in impurities, the values obtained under conditions A and B show that the possible effects during the time that the switch is closed for ignition of the iron wire (about two or three seconds) may be of such magnitude (40 to 60 calories) as to appreciably change the calorific value obtained for the materials tested. The use of the resistance coil in the circuit is a safe-guard against such possible errors.

Water Equivalent of the Calorimeter. The accuracy of the calorimetric values obtained is to an important degree dependent upon the accuracy with which the water equivalent of the apparatus has been determined. This may be determined by several methods:

(1) From the weights of the different parts multiplied by their specific heats.

(2) By adding definite weights of warmer or colder water to the system and noting the corresponding increase or decrease in temperature.

(3) By combustion of the same weight of material but varying the amount of water used.

(4) By electrical methods.

(5) By combustion of a substance of known calorific value, as napthalene, benzoic acid or cane sugar.

Four of these methods were tried in determining the water equivalents of the calorimeters used in this work.

First Method: Using the specific heats of the different materials as given by the manufacturer of the apparatus, the water equivalent of one of the calorimetrics used was calculated to be 470 calories. The sources of error are: (1) Any error in the values used for specific heat; (2) the enamel lining cannot be weighed and its weight must be calculated from its surface and approximate thickness and approximate specific gravity. The total amount of enamel is, however, so small, that the error from this source is necessarily small, probably less than one or two calories. (3) Portions of the bomb, bucket and stirrer are not in direct contact with the water and, therefore, are not affected to the same extent as the remainder of the apparatus by a change in the temperature of the water. An arbitrary deduction of three calories was made as a correction for that part of the bucket and stirrer not in contact with the water. This corresponds to about one third the calculated water equivalent of the portion out of water.

The valve stem of the calorimeter is entirely out of contact with the water and is more or less insulated from the lid, and is very little affected by a change in temperature of the water surrounding the bomb. A deduction of 17 calories from the total calculated water equivalent was allowed on this account. After making these two deductions, the value of water equivalent obtained is 470 calories.

Second Method: By adding warmer or colder water to the water surrounding the bomb. As finally worked up, the method used was in brief as follows: The flask containing the water to be added was well jacketed, so as to make the rate change small. A series of temperature readings was taken upon both the water surrounding the bomb and the water to be added and the rate of change of each system determined. The water was then added through a jacketed glass tube, the loss from radiation and from warming of the tube being experimentally determined and allowed for. This glass tube was attached to a thin brass tube flattened at the lower end to fit closely to the calorimeter and the opening so fixed as to deliver the water against the bomb, directly downward or outward. The length of this brass delivery tube was adjusted so that in some of the experiments the water was delivered about the middle of the bomb and in others at the bottom. After the addition of the water another series of readings was taken and from the temperature change and the amount of water added, the water equivalent of the apparatus calculated.

One series of seven determinations by adding colder water gave as the water equivalent 466 calories, the greatest variation of any single determination being within ten calories of this value. Another series of 16 determinations by adding warmer water gave an average for the water equivalent of 444 calories with extreme variations of 30 calories above and below this average. The average value of the two series is 455 calories. In this method the multiplication of errors makes the value for any individual determination very uncertain and the large difference between the results from adding colder and warmer water makes the average value rather unsatisfactory and uncertain, and our experience is not such as to cause us to recommend this method as an easy or satisfactory method for determining the water equivalent.

Third Method: Varying the amount of water used to surround the bomb during the combustion: Three series of determinations were made by this method using approximately 2100, 2400, and 2700 grams of water, but the results obtained were not satisfactory. In this method as in the previous method, the multiplication of errors during a determination makes the values obtained for any single determination very uncertain, and a considerable number of determinations must be made for each series to obtain an average at all satisfactory.

A possible variation in the actual working water equivalent of the calorimeter when different amounts of water are used makes the accuracy of the results obtained by comparison of the different series uncertain. With less water than usual more of the bomb, bucket and stirrer are out of direct contact with the water and the effective water equivalent is lower than when more water is used and correspondingly large amounts of the bomb, bucket and stirrer directly in contact with it. The extreme difficulty of securing satisfactory results, the effects of small changes in the water equivalent and the effects of errors of temperature readings may be shown best by a particular example:

With 2100, 2400 and 2700 grams of water in the calorimeter, the water equivalent of the apparatus may be represented by X, X′ and X″. During a determination a small amount of the temperature change is always caused by combustion of the iron wire fuse and the formation of a small amount of nitric acid (about 30 calories of heat developed by the two). The total water equivalent of the system 2100+X, 2400+X′, or 2700+X″ is approximately known, so that the temperature deduction due to these 30 calories can be allowed for to an accuracy of within .0001 of a degree. Deducting this temperature correction from the total temperature change and letting t=corrected temperature, the temperature due to combustion of material taken, the equation for the calories of heat developed by combustion of the material is:

(1) $t(2100 + X)$
(2) $t'(2400 + X')$
(3) $t''(2700 + X'')$

Suppose with 2100 grams of water in the calorimeter the water equivalent is Y calories lower and with 2700 grams of water is Z calories higher than with 2400 grams, then $X=X'-Y$ and $X''=X'+Z$.

The water equivalent of the Mahler calorimeter varies with each particular bomb, but ranges from about 450 to 500 calories.

Suppose X' be taken as approximately 500 and suppose that the calories of heat developed by the combustion of material used to be 8700 calories, then

$t'=3$ degrees, and
t and $t''=$ approximately 3.346 and 2.719 degrees.

Substituting for X and X″ (X′—Y) and (X′+Z) and equating 1 and 2,

$$X'=\frac{2400t'-2100t+Yt}{t-t'}$$

Equating 1 and 3

$$X'=\frac{2700t''-2100t+Yt+Zt''}{t-t''}$$

Equating 2 and 3

$$X'=\frac{2700t''-2400t'+Zt''}{t'-t''}$$

$t-t'=$approximately .346.
$t-t''=$approximately .63 and
$t'-t''=$approximately .28.

If Y=one calorie,

$$\frac{Yt}{t-t'}=\frac{3.346}{.346}=\text{approximately 10 calories.}$$

Also if Z=one calorie,

$$\frac{Yt+Zt''}{t-t'}=\frac{3.34+2.719}{.63}=\text{approximately 10 calories.}$$

and

$$\frac{Zt''}{t'-t''}=\frac{2.714}{.28}=\text{approximately 10 calories.}$$

In each case a variation of only one calorie in the water equivalent makes an error of +10 calories in the determination of the water equivalent.

There is no satisfactory and easy way of determining just how much the water equivalent does change with changes in amounts of water used, but the above values show that it may have a serious effect upon the actual figures obtained.

Further inspection will serve to show that the magnitude of the probable temperature errors also has an important effect upon the values obtained. The closest temperature readings on the thermometer are about .002 of a degree and an accuracy in the value of the temperature

readings in any series to within an error of less than .001 of a degree, certainly stands for extreme care and skill in manipulation and for very successful elimination of the errors incident to the use of the mercury thermometer. The effect of an error of .001 of a degree upon X′ by 1 and 2 is approximately

$$\frac{300 \times .001}{.34} = \text{approximately 10 calories;}$$

by 1 and 3

$$\frac{600 \times .001}{.63} = \text{approximately 10 calories;}$$

by 2 and 3

$$\frac{300 \times .001}{.28} = \text{approximately 10 calories.}$$

From this alone it is apparent that extreme accuracy by this method is not to be expected and taken together with the uncertainty due to the possible changes in the water equivalent the results obtained from this method can hardly be considered as very satisfactory.

Fourth Method. Electrical Standardization: This method depends upon the conversion of electrical energy into heat and involves the measurement of the electrical energy introduced and the temperature effect upon the calorimeter. The accuracy of the results obtained are dependent not only upon the accuracy of the measurements of the electrical units but also upon the absolute accuracy of the electrical units themselves. The writer has as yet not used the method, and hence has at present no comparative water equivalent values to offer. However, the very high grade instruments required in making the measurements puts it beyond the reach of most commercial and technical laboratories, and the most satisfactory available and the most commonly used is the next or fifth method.

Fifth Method. Calculation of the Water Equivalent from the Temperature Changes Produced by Combustion of Definite Amounts of a Material of Known Calorific Value: This is comparatively easy and there is no multiplication of errors, as in some of the other methods, and closely agreeing values are not extremely difficult to obtain. There are, however, some difficulties, one of which is to know the exact calorific value of the material used.

Naphthalene. This substance is quite commonly used as a standardizing material and has been taken as the standard for determining the water equivalent of the calorimeters used in determining the calorific values given for the samples of coal published in this report. Different lots of naphthalene differ quite considerably in calorific value, and the most satisfactory grade that the writer has been able to obtain is Kahlbaum's C. P. material. Merck's highest purity medicinal is not regarded as entirely satisfactory for calorimetric work, one lot running fifty to

sixty calories lower than the Kahlbaum material. The results on another lot of Merck's, apparently of the same grade but put up with more care, checked the results on Kahlbaum's reagent almost exactly.

The value of the water equivalent obtained for the calorimeter depends not only upon the purity of the naphthalene but also upon the figure taken as its calorific value, two quite different values being ascribed to it. Berthelot's value—9692 calories—has been used by Professor Lord and the writer for all standardization work, this value being used by Mahler. Stohlman gives as the calorific value 9628 calories and this value is used by Atwater. Using Kahlbaum's naphthalene and Berthelot's figure for calorific value, the water equivalent of the particular calorimeter previously mentioned is 460 calories. Using Stohlman's value it is only 441 calories. By using some lots of medicinally pure naphthalene the results for the water equivalent are about twenty calories higher than were obtained from the Kahlbaum naphthalene.

Benzoic Acid. The value given by both Berthelot and Stohlman for this material is 6322. Different lots of this substance may differ slightly in calorific value. Tests upon the best acid from gum benzoin gave results averaging a few calories lower than were obtained upon Kahlbaum's chemically pure matetrial. Using chemically pure acid the average from ten determinations is 443 calories for the water equivalent of the calorimeter. The average of three other determinations by another operator is 451 calories. The value from three determinations upon acid from gum benzoin is about 450 calories. From another series of five determinations run at a different time upon a different lot of acid from gum benzoin obtained from the same chemical supply house, but which had been standing around the laboratory for a year the value obtained for the water eqiuvalent is about 467 calories.

Cane Sugar. The values given by Stohlman and Berthelot agree within ten calories on this material, the average being 3958. One slight objection to cane sugar is that it does not ignite very readily and on this account in making a determination it is necessary to use a small amount of naphthalene or some other material of high calorific value to act as a kindler in starting the combustion.

Using ordinary granulated sugar: From one series of seven results the value obtained for the water equivalent is approximately 470 calories. Two results run on the same material by a different operator at a different time indicate approximately 467.

Using crystallized rock candy, one series of six results gave a value of about 455 calories as the water equivalent.

Collecting the different values:

(1)	By estimation from specific heats		470
(2)	By adding cold water	466	
	By adding hot water	444	
	Average	455	455

(3) By using different amounts of water during a combustion, results ranging from .....400 to 500
Not satisfactory.

(5) Burning material of known calorific value: — Kahlbaum's naphthalene (using 9692 as calorific value)..... 460
Kahlbaum's naphthalene (using 9628)..... 441
Benzoic acid (calorific value 6322) Kahlbaum's C. P..... 443
Highest quality from gum benzoin .....450 to 467
Cane sugar (calorific value 3958) Commercial granulated sugar .....467 to 470
Crystallized rock candy 455

This series of values to the inexperienced in calorimetric work may look rather ragged, but the writer believes that it is in full accord with the experience of chemists who have done large amounts of calorimetric testing extending through considerable periods of time, and the differences are given to call attention to the danger of determining the water equivalent in only one way, or upon only one lot of material. Some, but not all, of the differences in the values given are attributable to actual differences in the materials tested.

The differences in results obtained at different times on the same material are attributed by some chemists to differences in the quality of oxygen used; however, tests made at different times by the writer upon different lots of oxygen have in all cases indicated the absence of appreciable amounts of combustible impurities, and it appears that the different results given for the same materials are to be accounted for in some other way. In cane suar some of the high results are possibly due to failure of traces of the sample to burn completely, as with the shallow tray, usually used with a Mahler calorimeter, failures of cane sugar to burn completely are not infrequent. A deeper tray would very probably greatly decrease the number of unsatisfactory determinations.

The oxygen used in all calorimetric work done by the writer or under his direction has been furnished either by Arthur Hawkridge of Hoboken, New Jersey, or The White Dental Company of Philadelphia, Pa. The quality furnished by both of these manufacturers has so far been satisfactory.

As has been stated, the water equivalent used in the work upon coals is based upon Berthelot's value of 9692 for naphthalene and using Kahlbaum's C. P. material. In the series of values given, this value—460—is intermediate between the extremes of the values obtained from other substances or by other methods. The difference between the extreme values of 470 by specific heats and 443 from benzoic acid or 441 from Stohlman's value for naphthalene calculated to percentage effect on coals tested is equivalent to a difference in results of about nine-tenths of one per cent. That the actual water equivalent is between these extremes appears very probable and in the opinion of the writer, using 460 as the water equivalent of this particular calorimeter, the calorific value

obtained for the fuels tested should be correct to within an error of a few tenths of one per cent. Taking into consideration what has already been given, it is hoped that the expression of this opinion will not subject the writer to the criticism that he under-estimates the difficulties of accurately determining the actual water equivalent of a calorimeter.

CALCULATING AND REPORTING OF RESULTS.

The analysis and calorific value of each of the samples is given in connection with the sections of the seams in that portion of the report prepared by Dr. Bownocker. These analyses are for further comparison and discussion tabulated at the end of the chapter, written by Professor Lord, the results on the samples of each of the different seams being grouped together. The analyses on the samples of Nos. 4, 5, 6 and 7 coals collected during 1900, 1901, and 1902 are all upon the partially air-dried samples. These results, as has already been stated under the "Method of Sampling," are therefore all lower in moisture than the sample as mined, while the calorific value, sulphur and ash are correspondingly higher. The samples of No. 8, 8a and 9 coals collected in 1907 are all reported upon the sample as received at the laboratory. Being shipped from the mine to the laboratory in sealed cans, the analysis is therefore upon the sample as mined.

On air drying under ordinary weather conditions, these coals all lose moisture and the results as given are higher in moisture and lower in calorific value than the values obtained upon the air-dried sample. "Air-dried Sample" is, however, such a variable quantity depending upon the particular temperature and humidity conditions existing at the particular time the sample is handled that an effort to report the samples upon an air-dried basis is not very satisfactory.

The chief value of air drying a sample before analysis is to obtain the sample in such a condition that its variations in the laboratory while being analyzed are small. The air drying loss is, however, an approximate guide to the loss that the coal may suffer during shipment. The foot-note values give the approximate moisture in the air-dried sample. The difference between the moisture in the sample as received and the moisture in the air-dried sample indicates the possible loss which the coal may undergo before arriving at an air-dry condition in ordinary summer weather. Complete air drying of a shipment, is, however, the exception rather than the rule, as lump coal or coal in piles of any considerable depth holds a considerable amount of this excess moisture even in dry weather, and in damp weather the loss is of course small, and in very wet weather the moisture content may often exceed the moisture content in the coal as mined, especially if exposed to rain or snow, and if a shipment contains much slack coal.

As the samples collected during 1907 are all reported upon the

sample as mined, if the results are compared with the earlier samples taken or with analyses of samples as ordinarily shipped, this fact must be taken into consideration in making the comparision. The results obtained upon the samples collected during 1907 show that the moisture content of the coal as it occurs in the mine varies very considerably. In the No. 9 coal it ranges from 3 per cent. to 5.3 per cent., the average being about 4.1 per cent. In the No. 8a coal it ranges from 3.4 per cent. to 8.2 per cent., the average being about 6.8 per cent. In the No. 8 coal it ranges from 2.8 per cent. to 7 per cent, the average being about 4.7 per cent. In the samples of No. 6 coal taken during 1907, the moisture ranges from 3.6 per cent. to 8 per cent., the average being about 6.3 per cent. In the samples of No. 5 coal, the range is from 2.5 to 8.4, the average being about 6 per cent.

After air drying the moisture still contained in the samples averages for the No. 9 coal about 2 per cent., in the No. 8a coal about 4 per cent., in the No. 8 coal about 3 per cent. and in the No. 5 and No. 6 samples tested about 2.5 per cent.

The heating values of the samples are all given in calories. For discussion of the relation of the calorie to the British thermal unit, see chapter by Professor Lord, page 267. For explanation of the meaning, use and value of "H," see same chapter, page 268. For explanation of the calculation of the heating value from the ultimate analysis by means of Dulong's formula, see same chapter, page 267.

Special Tests for Air-Drying Loss. To determine the rate and extent of air-drying loss upon exposure to the ordinary air of the laboratory, special tests were made upon several samples. The original samples crushed to ¼ inch were weighed upon trays 24x24 inches and allowed to stand at room temperature for a number of days. Weighings were made from time to time and the temperature and humidity at the time of the weighings reported. Two samples dried for ten days, one of No. 8 coal, sample No. 26, and one of No. 9 coal, sample No. 53, gave results as follows:

Sample No. 26:

Time between Weighings.	Weight	Temperature.	Humidity.
	1500 grams	26	67
3 days	1465 "	23	53
1 day	1455 "	24	18
1 day	1441 "	24	49
1 day	1441 "	23	53
4 days	1441 "	24	54

The total loss in the ten days is 59 grams, equal to 3.93 per cent. This coal still contains by analysis 3.65 per cent. moisture. Sample No. 53 as received contained 2.95 per cent.; dried to constant weight under the same conditions as No. 26, the air-dried sample contained 1.66 per cent. moisture.

In the regularly analyzed samples dried in the drying oven the moisture contained in the air-dried samples ranges in the No. 9 coal between 1½ and 3 per cent., in the No. 8a coal between 3½ and 4½ per cent., and in the No. 8 coal between 2 and 4 per cent.

Tests for air drying loss and moisture remaining in air-dried samples were also made upon portions of three samples of No. 5 and No. 6 coal with the following results:

Time between weighings. Hours.	Temperature.	Humidity.	Sample No. 826.		Sample No. 76		Sample No. 138	
			Wt.	Loss.	Wt.	Loss.	Wt.	Loss
0	21½	32	2907	0	3029	.....	2043	....
6	23	30	2850	57	2972	57	1986	57
16	22	31	2807	43	2918	54	1957	29
24	25	27	2784	23	2987	31	1943	14
48	20	50	2776	8	2982	5	1951	8
24	20	33	2773	3	2978	4	1943	8
118				134		151		100

The total time of air drying was 118 hours and the total loss of each sample is as follows:

Sample No. 826.
134 grams loss equals 4.60 per cent.
Sample No. 76.
151 grams loss equals 4.98 per cent.
Sample No. 138.
100 grams loss equals 4.89 per cent.

The air-dried portions of these samples still contained moisture as follows:

Sample No. 826.	3.41 per cent: Moisture.
Sample No. 76	3.20 per cent: Moisture.
Sample No. 138	2.32 per cent: Moisture.

In the regularly analyzed samples of No. 5 and No. 6 coal collected during 1907, which samples were air-dried in the drying oven, the moisture in the air-dried samples ranges from 1½ to 3 per cent.

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1—S. G.—1,000.

FOURTH SERIES, BULLETIN 10

THE MIDDLE DEVONIAN OF OHIO

By CLINTON R. STAUFFER

NOVEMBER, 1909.

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OF THE
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Dr. J. A. Bownocker, *State Geologist,*

Dear Sir:—I send you herewith the manuscript on "The Middle Devonian of Ohio." The work, on which this report is based, has been under way during a considerable portion of the last four years. It is complete only in so far as any such work may be; but it is submitted as a rather careful study of these formations, and with the hope that it may contribute something to a better knowledge of this important period in the geological history of our State.

Respectfully submitted,

(Signed) Clinton R. Stauffer.

Western Reserve University,
October 11, 1909.

INTRODUCTION.

It is proposed to bring together, in the following discussion, the more important facts that have previously been published regarding the Middle Devonian formations of Ohio; to discuss the sections and faunas of a number of characteristic outcrops scattered over the entire area of outcrop within the State; to discuss the relationships of the faunas; and to give a few notes on certain species, together with figures and descriptions of certain others which have thus far remained undescribed.

During the progress of this study, encouragement and helpful suggestions have been received from a number of friends and fellow-workers. But more specific mention should be made of Dr. Charles S. Prosser for valuable assistance in the identification of difficult specimens, and for actual accompaniment in some parts of the field, as well as for advice in regard to the general outline of the work; Dr. J. A. Bownocker, whose suggestions and kindly interest have made the burdensome part of the work a much easier task; and especially Dr. Stuart Weller, whose knowledge of species and faunas has been a constant aid. All three of these gentlemen have had a part in the criticism of the manuscript and have thus contributed to the value of the finished work.

Nor would this portion of the report be complete without the mention of Miss Edith Hyde, who did the illustrative work on the fossils. In addition to being an artist, Miss Hyde is a paleontologist and as such has rendered valuable assistance in the case of specimens submitted to her.

C. R. S.

CHAPTER I.

GENERAL DISCUSSION OF THE MIDDLE DEVONIAN.

HISTORICAL SKETCH.

The Middle Devonian formations of Ohio, lying as they do along the shores of an island in the midst of one of the great Devonian seas, form an interesting and important chapter in the history of that period, and the limestone portions have been a subject of study since the organization of the first Geological Survey of the State.

In the First Annual Report (1838) Kirtland describes "The Great Limestone Deposit," which he says according to Riddell is divided into "the blue limestone district" and "the yellow limestone district," the latter of which extends "from Adams, Highland, Green and Montgomery counties northward to Michigan and Lake Erie, and from the shale regions on the Huron and Olentangy westward, doubtless, beyond the State boundary."[1] As we now know this region includes not only the Devonian limestones, but those of the Silurian as well.

The Second Annual Report appeared the same year, and in it J. W. Foster gave a "Geological Section along the National Road from the Scioto River to the eastern line of Muskingum county, in the State of Ohio," in which he represents a portion of the rocks designated the "Mountain limestone with beds of chert."[2] In his section giving the "Geological Structure," Number VI is named the "Mountain Limestone" which, he says, consists of "Beds of limestone intermixed with chert."[3] And again "The series [shale] last described reposes on a formation composed of beds of limestone to which the terms 'Mountain' and 'Transition' have been applied. The color of this limestone varies from a light gray to blue. It is subcrystalline in its texture, and is stratified in layers from a few inches to three of four feet in thickness, being divided by thin beds of clay or marl. It is also intermixed with chert or hornstone." It outcrops "near the residence of Mr. W. Sullivant, about three miles west of Columbus," and "is the material of which the Penitentiary is constructed."[4] There can be no doubt concerning the mass of rocks here referred to, and yet statements made by Foster in the same connection indicate that he used the above term in a manner synonymous with that of "Cliff limestone" used by Locke for the rocks of the whole "yellow limestone district."[5] The term "Mountain limestone," it will be recalled,

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[1] 1st. Ann. Rept., *Geol. Surv. Ohio*, 1838, p. 76.
[2] 2d Ann. Rept., *Geol. Surv. Ohio*, 1838, opp. p. 73.
[3] *Idem.*, p. 76, [4] *Idem.*, p. 106. [5] *Idem.*, p. 211.

2—S. G.—1,000.

is the name applied by various English geologists to the Carboniferous [Mississippian] limestones occurring in Great Britain. It has subsequently been applied to limestones belonging to that system in various states of the Union. So it would seem that Foster regarded these limestones in Ohio as Mississippian.

Thus it appears that during the pioneer Geological Survey, the Devonian limestones were not differentiated from the older formations belonging to the Silurian, nor from the more recent formations of other states, but this distinction remained for James Hall who first identified the "Corniferous limestone" in Ohio.[1] In referring to this fact, he says: "A short distance to the west of that place [Columbus], the Corniferous limestone of New York appears, presenting its characteristic fossils. This mass is the upper part of the Cliff limestone formation of Dr. Locke, the name by which it is generally known in Ohio. The localities where I saw this rock exhibited less hornstone than is usual in New York, but the position and fossil characters were unequivocal."[2] This definite statement by so eminent a geologist must have meant much to those directly interested in the geology of our State, for, so far as now appears, it was the first real truth that had been uttered concerning the correlation of Ohio formations with those of the East, and probably served as the gateway through which other facts became known.

In the middle forties de Verneuil studied the Devonian deposits of Indiana and Kentucky, and in his discussion of the correlation of these formations with those of New York says that "in the states of Ohio, Indiana and Kentucky it [Devonian] is reduced to the black schists which represent the Genesee slate, and to a calcareous band which represents at once the Corniferous and Onondaga limestones and the Hamilton group of the state of New York."[3] He thus supports Hall's conclusions.

Newberry, Chief Geologist of the Second Geological Survey of Ohio, accepted Hall's correlation and under his direction the "Corniferous" was studied in some detail appearing with the above name on his "Preliminary Geological Map of Ohio,"[4] and in the accompanying report he describes it together with a mention of some of its fossils.[5] Again in the first volume of the Geological Survey of Ohio he gives a rather complete description of the "Corniferous," dividing it into two well marked divisions. "Of these the uppermost is a blue, thin bedded limestone, from fifteen to twenty feet in thickness, and is the rock quarried at Sandusky and Delaware. This I have usually designated as the Sandusky limestone.[6] Below this we find a very light-colored limestone which

[1]*Geol. Sur. Ohio*, Vol. I, pt. 1, 1873, p. 142.
[2]*Geol. N. Y.*, pt. IV, 4th Dist, 1843, p. 503.
[3]Hall's translation, *Am. Jour. Sci.* 2nd Ser. Vol. V, 1848, p. 370.
[4]*Geol. Surv. Ohio, Rept. Prog. for* 1869, (1870), opp. title page.
[5]*Idem*, p. 17.
[6]See Dr. Prosser's article on the Delaware limestone, *Jour. Geol.*, Vol. XIII, 1905, pp. 425-442, and his historical review of the Devonian limestones in Ohio on pp. 413-425.

often contains balls and masses of chert. It is strikingly different in its mineral character, and somewhat different in its fossils from the overlying bed; though a large number of species are common to both. This lower subdivision I have called the Columbus limestone, as it is the rock opened in the quarries near that city."[1]

In N. H. Winchell's report on the Geology of Crawford county, a similar statement is found. He says that "It [Corniferous] is distinctly divisible, on paleontological and lithological differences, into two parts, the upper part embracing the blue limestone, which shows some relations to the Hamilton, and the lower part embracing the light-colored and dolomitic limestones * * * . The former * * * is extensively wrought at Delaware and Sandusky. The latter is quarried at Marblehead * * * and at Columbus."[2]

It is evident, therefore, that both of these men were impressed by the different characteristics exhibited by the two portions of the terrain, but there was a decided difference of opinion as to the upper or so-called "Sandusky limestone." Winchell considered it as representing a portion of the New York Hamilton. He had been connected with the Michigan Geological Survey, where the Traverse group is rather definitely correlated with the Hamilton of the East, and out of the twenty-three Ohio counties represented to have exposures of the Devonian limestones, Winchell studied and reported on fifteen, while the other eight county reports are the work of five different men. As a consequence he must have had abundant opportunity to examine the formations in their various phases of outcrop. Concerning the upper limestone, or that which we now know as the Delaware, he remarks that "Hamilton fossils prevail over those having a distinctive Corniferous character, both in Michigan and in Ohio throughout this blue limestone."[3] Newberry on the other hand regarded it as the upper portion of the "Corniferous." He had examined carefully the exposures of Erie county and made a general investigation of the outcrops of other portions of the state. Concerning these he says, "In all the exposures, however, which I have examined of this member [Upper Corniferous] of the series, I have found Corniferous fossils greatly predominating, and the truly Hamilton species confined to the uppermost layers."[4] These statements, and many others of a similar nature made by the same scientists, are conflicting, even contradictory, but are readily understood when we consider the fact that the two gentlemen were, in reality, discussing two different limestones, thus making it possible for both to be, in a measure, correct. Newberry took as his type section that found at the quarries in the vicinity of Hancock street and Sycamore line, Sandusky, which, with the exception

[1]*Geol. Surv. Ohio*, Vol. I, pt. 1, 1873, p. 143.
[2]*Idem.* Vol. II, pt. 1, 1874, p. 244.
[3]*Proc. Am. Ass'n. Adv. Sci.*, Vol. XXII, pt. 2, 1874, p. 102.
[4]*Geol. Surv. Ohio*, Vol. I, pt. 1, 1873, p. 151.

of the uppermost layers, has since been shown to be Columbus limestone.[1] Winchell based his conclusions on the section at Delaware, but probably more especially on the outcrops of the northwestern part of the state; his study was therefore of a formation lying above that to which Newberry referred, or of the true Delaware limestone. Perhaps, however, Winchell was carrying his correlation ideas rather far when he introduced the name Tully limestone,[2] for the top layers, at most "about nine and one-half feet" of the "Upper Corniferous."

In his "Report on the Geology of Franklin County," Orton, who agreed in general with the Newberry classification, speaks of the upper part of the "Corniferous" as "the blue limestone, thirty-two feet in thickness, which is, from its occurrence at Delaware, and the extensive use made of it at that point, well named the Delaware limestone."[3] Winchell had used this term four years earlier for the same mass of rocks,[4] but regarding this use he says: "I used the term Delaware stone or Delaware limestone as a constituent of the geology of Delaware county only, although I referred to its extension (paleontologically at least) northward to Sandusky county. The idea that it would ever be used as a formational name, even for the county, was not in my mind."[5] Prosser has credited the name to Orton,[6] who appears to have given it a definite formational meaning. In referring to the correlation of the Ohio with the New York Devonian, Orton says: "The Devonian limestones * * grew in a sea in which the same general conditions were maintained, while very different strata were in process of formation at the East. The Columbus and Delaware limestones probably cover the age in which the Corniferous limestone, and the Hamilton group, in part, of New York were forming; * * * A disturbance of previous conditions took place in this interior sea, which is marked by the change from the Columbus limestone to the Delaware limestone, but any correlation of this change, with epochal changes at the eastward, is, so far as the facts appealed to indicate, entirely arbitrary."[7] We thus see that while Orton sympathized with the position which Winchell had taken, he did not consider a definite correlation possible.

While discussing the outcrops of the Devonian limestones at the

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[1]Prosser, Charles S., *Jour. Geol.*, Vol. XIII, 1905, p. 441; also Swartz, Charles K., *Johns Hopkins Univ. Cir. N. Ser.*, No. 7, 1907, p. 56.

[2]*Geol. Surv. Ohio*, Vol. II, pt. 1, 1874, pp. 240, 288, 291, etc.

[3]*Idem*, Vol. III, 1878, p. 606.

[4]*Idem*, Vol. II, pt. 1, 1874, pp. 294, 295.

[5]Letter of Feb. 1st, 1906.

[6]*Geol. Surv. Ohio*, 4th Ser., Bull. No. 7, 1905, pp. 3, 24.

[7]*Geol. Surv. Ohio*, Vol. III, 1878, pp. 633, 634.

Falls of the Ohio, James Hall says that "in the state of Ohio, Dr. Newberry recognizes the following:

Hamilton shale.
Hamilton limestone.
Corniferous group { Sandusky limestone.
Delhi beds.
Columbus limestone."[1]

Just what the significance of such a classification[2] may be, is somewhat problematic, since in the section at Prout Station the "Hamilton limestone" lies above the "Hamilton marl."[3] It is very certain that Newberry did not then refer to the Delaware when he used the term "Hamilton limestone." Hall probably misquoted Newberry, and yet the error, if such it be, was made on the side of truth.

Finally R. P. Whitfield, who visited Ohio in 1878 and made some geological excursions with Orton, found a bed of dark brown shale forming the base of the Delaware limestone along Slate Run six miles northwest of Columbus, and likewise on the east bank of the Scioto nearly opposite the village of Dublin. In this shale he collected a fauna which led him to declare it to be "the equivalent of the Marcellus shale of New York."[4] Charles S. Prosser says that this is "the most important discovery relating to the classification of the Devonian limestones that had been made in central Ohio."[5] If this identification is correct, it settles at once the limitations of the "Corniferous" proper and the necessary Hamilton age of the Delaware limestone. Concerning this occurrence of the Marcellus shale, Whitfield himself says: "The geological importance of this formation among the rocks of Ohio, may not be readily recognized; but, forming as it does, a dividing line between the lower and upper Devonian, as between the limestone of the Upper Helderberg and those which are properly referable to the Hamilton period, it will have great value."[6] But so great had been the opposition to this correlation that even Whitfield's conclusion, although restated in the Geology of Ohio,[7] was not well received.

In order to lessen the objections made by various geologists to the classification then in use, Orton introduced the New York term "Upper Helderberg limestone," which he considered "a more comprehensive term."[8] Prosser, however, says that "the substitution of the name 'Upper Helderberg limestone' for 'Corniferous limestone' did not meet any of the objections raised by Winchell, Hall and Whitfield to the New-

[1] *Pal. N. Y.*, Vol. V, pt. II, 1879, p. 141.
[2] *Geol. Surv. Ohio*, Vol. VI, 1888, pp. 763, 766.
[3] *Geol. Surv. Ohio*, Vol. II, pt. 1, 1874, p. 190.
[4] *Proc. Am. Ass. Adv. Sci.*, Vol. XXVIII, 1879, p. 298.
[5] *Jour. Geol.*, Vol. XIII, 1905, p. 418.
[6] *Op. cit.*, p. 299.
[7] *Geol. Surv. Ohio*, Vol. VII, 1893, pp. 432-433.
[8] *Geol. Surv. Ohio*, Vol. VI, 1888, p. 20.

berry classification of the Devonian limestones of Ohio, because, so far as the later formations are concerned, it is not a more comprehensive term than the 'Corniferous limestone,' and in its classic locality, the Helderbergs of eastern New York, has never been applied to rocks above the base of the Marcellus shale."[1] Indeed the matter became so much the more complex by the appearance in the State geological literature of another name representing the same formations.

Bownocker, in his paper on "The Paleontology and Stratigraphy of the Corniferous Rocks of Ohio," while discussing the "Relation of the Fauna above the Bone-bed to that Below," at the various places visited, states that "this difference is most conspicuous at Delaware and diminishes to the north, being least at Sandusky."[2] It is quite probable, however, that at the time of his writing the "bone-bed" had not been definitely located at the latter place, as his collection from the "upper limestone" was made from the quarries near Hancock street and Sycamore line, and hence from the Columbus limestone.

In 1889 Newberry published a paper, entitled "Devonian Plants from Ohio," in which he mentions "the Delaware limestone, the upper division of the Corniferous" and again "the white or Sandusky limestone below."[3] About six years later James D. Dana published the fourth edition of his Manual and in it, while referring to the occurrence of the "Corniferous" in Ohio, he says, "two divisions are made out—the lower, named the Columbus or Sandusky, and the upper, the Delaware limestone."[4] In this it seems certain that Dana was following Newberry, since he calls both of these limestones "Corniferous," which under the other classification would probably not have been done. These statements seem to indicate that Newberry had yielded his earlier opinion regarding the rocks at Sandusky and now correlated them with the Columbus limestone, or lower division of his "Corniferous" instead of with the Delaware limestone as he had heretofore done. Charles K. Swartz, who has made a rather extensive study of the Ohio Devonian limestones, has also referred most of the rocks of Newberry's "Sandusky limestone," in the vicinity of the city of which it bears the name, to the Columbus limestone.[5] This correlation has been verified and, in the main, accepted by Prosser,[6] who, in his "Revised Nomenclature of Ohio Geological Formations," uses Columbus and Delaware as the formational names for these limestones.[7]

Hayes and Ulrich give a correlation table in the last column of

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[1] *Jour. Geol.*, Vol. XIII, 1905, p. 420.
[2] *Bull. Sci. Lab. Den. Univ.*, Vol. XI, 1898, p. 39.
[3] *Jour. Cin. Soc. Nat. Hist.*, Vol. XII, 1889, p. 49.
[4] *Dana's Man. of Geol., 4th Ed.*, 1895, p. 581.
[5] *Loc. cit.*, p. 56.
[6] *Jour. Geol.*, Vol. XIII, 1905, p. 441.
[7] *Geol. Surv. Ohio, 4th Ser., Bull. No. 7*, 1905, pp. 3, 24, 25.

which, under the head of "Geological Survey of Ohio, 1873-93," they give the following for the Devonian:

"Black or Ohio shale (1893).
(Including Cleveland shale, Erie shale and Huron shale.)
Olentangy shale and Delaware limestone.
(Hamilton.)
Columbus limestone.
(Corniferous.)"[1]

No discussion follows, but of course they have followed Winchell and Whitfield.

During the same year (1903) Edward Claypole's article on "The Devonian Era in the Ohio Basin" appeared. He states that "the planes of division between these groups—the Corniferous and Hamilton—are less sharp in Ohio than in New York, where the transition from the pure limestones of the Corniferous to the black shales of the Hamilton is comparatively abrupt."[2] He therefore calls the Delaware limestone "Corniferous-Hamilton" and says "the facts warrant the statement that Corniferous conditions prevailed in Ohio throughout the whole of the Hamilton period in New York, with a few temporary and local interruptions."[3] He correlates the shaly zone at the base of the Delaware with the Marcellus shale,[4] thus bringing in, at least in some parts of the state, a return of "Corniferous" conditions after the deposition of that formation.

Grabau relieves us somewhat regarding the idea that the Hamilton shales of the East must necessarily be represented by shales in the West. While discussing the Eighteen Mile Creek sections, and especially the Encrinal limestone, he remarks that "in Illinois, Iowa, Michigan, Ohio, Indiana and other central states, however, the Hamilton is chiefly represented by limestones, often of considerable thickness."[5] The only Ohio limestone, of any "considerable thickness," that may be classed as Hamilton is, of course, the Delaware and we might infer that he had it in mind when writing the above statement were it not for the rather misleading remark that "the 'black shale' of Ohio and other states represents these deposits [Marcellus], which continued uniformly during all the time that the Hamilton beds were being laid down over New York."[6]

"The Traverse fauna," Schuchert says, "is a commingling of Mississippian and Dakota species. This mixed Middle Devonic fauna is continued southward as far as Louisville and Lebanon, Kentucky, on the west side of the Cincinnati island, while immediately on the eastern side of this island at Columbus, Ohio, the faunal sequence is more decidedly

[1] *U. S. Geol. Surv.*, Columbia folio, No. 95, 1903.
[2] *Am. Geol.*, Vol. XXXII, 1903, pp. 34, 35.
[3] *Idem*, p. 36.
[4] *Idem*, p. 35.
[5] *Bull. Buf. Soc. Nat. Sci.*, Vol. VI, No. 1, 1898, p. 80
[6] *Idem*, p. 82.

that of New York. The paleontologic work of Whitfield on the Devonic beds of central Ohio shows unmistakably that the succession here is in agreement with western New York, i. e. the Manlius is followed by the Onondaga, Hamilton, Portage and Chemung faunas. In other words, the New York Hamilton fauna retains its characters more strongly along the shores of Laurentia, Appalachia and the eastern side of the Cincinnati island, while the Traverse Hamilton fauna followed the eastern shore of the Kankakee peninsula and the western side of the Cincinnati island."[1] Schuchert's position is thus decided and unmistakable, as is also that of Weller, who states that "in Ohio the [Corniferous] fauna occurs in the Columbus limestone,"[2] thus distinctly separating that formation from the Delaware. Prosser writes that "the Sandusky (Delaware) limestone ought to be correlated with rocks of later age than the Onondaga limestone, viz: the lower part of the Erian series of New York."[3] Foerste remarks that "in Ohio, on the eastern side of the geanticline, the Sandusky or Delaware limestone has been identified as the lower part of the Erian."[4] More recently, however, this same author says that "in Ohio these [Devonian] limestones include, in descending order:

c. Delaware limestone.
b. Columbus limestone.
a. A comparatively unfossiliferous section of limestone for which no distinctive name has been proposed as yet.

For these three Devonian limestones of Ohio the name Scioto limestone would be very appropriate."[5] It is obvious that if the Delaware limestone belongs to the Erian series it should not be united under one formational name, with the Columbus limestone which is a representative of the Ulsterian series. As to his lower unnamed division "a" of the Columbus limestone, there seems to be insufficient reason for separating it, if he means to make a distinct formation, since its meager fauna is that of the remainder of the formation as at present defined. Schwartz has made three divisions of the Columbus limestone, but he uses them consistently as subdivisions which are not of formational rank, although he does propose names for each.[6]

The Devonian shales of Ohio have never received the same amount of attention in literature as have the limestones. They have not passed through the conflict of opinions that has characterized the limestones, but have gone more directly to their present correlation. While discusing the geological sections of Ohio, Newberry refers to "a band of bluish marly limestone, * * * resting upon the Corniferous lime-

[1] *Am. Geol.*, Vol. XXXII, 1903, p. 148.
[2] *Jour. Geol.*, Vol. X, 1902, p. 424.
[3] *Jour. Geol.*, Vol. XI, 1903, p. 537; also *Geol. Surv. Ohio, 4th Ser., Bull. No. 7*, 1905, p. 24, Note 21.
[4] *Jour. Geol.*, Vol. XI, 1903, p. 702.
[5] *Geol. Surv. Ky., Bull. No. 7*, 1906, p. 12.
[6] *Op. cit.*, pp. 63-65.

stone where that is overlaid by more recent rocks. From this marly limestone we have obtained many of the characteristic fossils of the Hamilton group."[1] This deposit occupies the same horizon as the blue shale which Winchell discusses in the report on Delaware county, and which he says "has been regarded the equivalent of the Hamilton. There are no fossils in this underlying shale at Delaware proving its Hamilton age, and it will be referred to * * * , to avoid a possible misuse of terms, as the Olentangy shale."[2] This shale at the type section (a quarter of a mile below the railroad bridge over the Olentangy River at Delaware) contains a number of layers of marly limestone and, although nearly destitute of fossils, is doubtless the equivalent of the marly limestone to which Newberry refers, as well as of his Hamilton limestone and marl at Prout Station and Deep Cut[3] near Sandusky.

THE MIDDLE DEVONIAN IN ADJOINING TERRITORY.

In the adjoining state of Indiana, the Middle Devonian limestones have long been correlated with eastern formations.[4] Edward M. Kindle, who has made a systematic study of these outcrops in Indiana, recognizes three distinct formations. In the order of their natural sequence they are as follows: The *Geneva limestone*, which "is generally a massive light buff to chocolate brown saccharoidal magnesian limestone" in which "fossils are extremely rare at most localities * * * and occur usually as casts when found;"[5] the *Jeffersonville limestone*, a very fossiliferous "gray or bluish gray crystalline or subcrystalline limestone, occurring both as a massive and a thinly stratified limestone;"[6] and finally the *Sellersburg beds*, also quite fossiliferous and comprising "a bed of fine grained argillaceous drab grayish-colored limestone * * * and a thin bed of light gray or bluish crystalline limestone above it."[7]

In discussing the "Correlation of faunas" in the last two of these formations as found in the southern Indiana district near the Ohio River, Kindle says: "The Corniferous fauna of New York suffers no very important modifications in its western extension. The large number of species common to the faunas of the Corniferous limestone of New York and the Jeffersonville limestone, especially among the Corals, leaves no doubt as to the equivalence of the two faunas. * * * In southern Indiana we find in the Sellersburg beds a fauna containing many of the most characteristic species of the Hamilton of New York. * * * This fauna is not mingled with the Corniferous as was once supposed, but occurs above that fauna in the Sellersburg beds. The presence in it of such characteristic Hamilton fossils as those mentioned seems to

[1] *Geol. Surv. Ohio, Rept. Prog. 1869*, (1870), p. 18.
[2] *Geol. Surv. Ohio*, Vol. II, pt. 1, 1874, p. 284.
[3] *Geol. Surv. Ohio*, Vol. II, pt. 1, 1874, pp. 189, 190.
[4] Hall, James, *Pal. N. Y.*, Vol. V, pt. 2, 1879, pp. 139-154.
[5] *25th Ann. Rept. Dept. Geol. and Nat. Res. of Ind.*, 1900, p. 535.
[6] *Ibid*, p. 535.
[7] *Ibid*, p. 533.

leave no doubt of its equivalence to the New York Hamilton."[1] He adds later that "In the northern part of the southern Indiana area these two formations cease to be sharply differentiated lithologically and merge into each other in a limestone which is neither so pure as the Jefersonville limestone nor so argillaceous as the Sellersburg beds near the Falls. Associated with the loss of individuality of these two formations occurs a mingling of their two faunas which renders them indistinguishable as separate faunas." But "in the Wabash area the faunas of the Devonian limestones are even more distinct than that at the Falls of the Ohio."[2]

At the Ohio River the Geneva limestone has thinned out, but the upper two formations may be traced across into Kentucky at Louisville, where the cement layers of the Sellersburg beds furnish the material for a large industry, while in the upper part of the cliffs near the east-side waterworks the Jeffersonville limestone may be seen. The total thickness of the Devonian limestones in Kentucky is reported as about forty feet, although usually much less, and "In outcrop they follow on the map the outcrop of the Devonian Black shale from the Ohio River in Lewis county around to the Ohio River again at Louisville, at which place they form the falls in the river."[3]

In Michigan two divisions are recognized; the Dundee, a gray subcrystalline limestone varying from massive to comparatively thin bedded layers abounding in fossils, and the Traverse, which is more or less impure, frequently being largely shale and attaining a considerable thickness in the northern part of the lower peninsula. These formations are correlated with those of New York in the following manner:

New York	Michigan
Hamilton beds Marcellus shale	Traverse group
Onondaga limestone Schoharie grit Esopus grit	Dundee limestone
Oriskany beds	(hiatus?)[4]

These same formations cross over into Ontario, Canada, near the city of Detroit and blend with the great deposits to the north, where they become materially thickened. Here also two divisions are recognized; the Corniferous limestone which "appears in Canada to have a thickness of about one hundred and sixty feet, and is estimated by Sir William Logan to cover an area of probably not less than six or seven thousand square miles. * * * Throughout almost its whole extent it is richly fossiliferous,"[5] and the Hamilton group which "In Canada * * * is well represented by argillaceous and cal-

[1] *Bull. Am. Pal.*, Vol. III, No. 12, 1899, p. 110.
[2] *25th Ann. Rept. Dept. Geol. and Nat. Res. Ind.*, 1900, p. 570.
[3] *Geol. Surv. Ky., Bull. No. 1*, Prelim. Pt., 1904 (1905), pp. 34, 35.
[4] *Geol. Surv. Mich.*, Vol. VII, pt. 1, 1900, p. 37.
[5] *Rept. Pal. Prov. Ont.*, 1874, p. 9.

careous shales with intercalated beds of limestone, the whole having an estimated thickness of about three hundred feet."[1] These Nicholson has correlated with the New York formations in the following manner:

"State of New York	Equivalent in Ontario
Onondaga limestone Corniferous limestone	Corniferous limestone
Marcellus shale Hamilton shales Tully limestone	Hamilton group."[2]

Thus Ohio is in the midst of a region within which true Onondaga and Hamilton deposits are identified. The sum total of previous work on the Middle Devonian within the state has been more or less unsatisfactory, in so far as published records show. It remains, therefore, to bring out the results of a rather extensive investigation of the outcrops of these formations in different parts of the state.

GENERAL DESCRIPTION OF THE MIDDLE DEVONIAN.

The Devonian is represented in Ohio by the Middle and Upper divisions only. These, with their associated formations, are at present classified in the following manner:

- Mississippian
  - Upper
  - Middle
  - Lower — Waverly
    - Logan formation
    - Black Hand formation
    - Cuyahoga formation
    - Sunbury shale
    - Berea grit
    - Bedford shale
- Devonian
  - Upper
    - Chautauquan and Senecan — Ohio shale
      - Cleveland sh.
      - Chagrin form.
      - Huron shale
  - Middle
    - Erian
      - Olentangy shale
      - Delaware limestone
    - Ulsterian — Columbus limestone

UNCONFORMITY

- Silurian
  - Upper — Cayugan — Monroe form.
    - Lucas ls.
    - Sylvania ss.
    - Tymochtee form.
  - Middle
  - Lower

[1] *Rep. Pal. Prov. Ont.*, 1874, p. 9. [2] *Idem*, p. 10.

South of Pickaway county the limestones of the Middle Devonian, and even the upper part of the Silurian, drop out, so that the Olentangy shale comes to lie upon the Niagaran limestones, while at some places in Pike county even the Olentangy is absent and then the black shale rests directly on the Niagaran.

The Middle Devonian formations, occupying the lower portion of the Devonian System in Ohio, form a belt of outcrop along either side of the Cincinnati anticline, with an outlying portion in the vicinity of Bellefontaine.[1] The eastern of these belts, which has an average width of about ten or twelve miles, extends from the islands in Lake Erie, north of Sandusky, southward to the Ohio River and beyond, although the limestones disappear in Pickaway county. This belt of outcrop is by far the more important both from an economic and a purely scientific point of view, because it is a source of great quantities of lime, crushed stone, furnace flux, and building stone, and its lower member, the Columbus limestone, contains one of the richest faunas found within the borders of the state and probably not excelled by any other Devonian deposit. In Franklin and Delaware counties the Scioto and Olentangy Rivers have cut through the drift and into these formations, while northward the drift is thin and quarries have been opened in the limestones at numerous localities; hence the opportunities for their study are abundant.

The Bellefontaine district consists of a rather broad belt of outcrop surrounding the Ohio shale capped hills extending from the southern portion of Hardin county across Logan and into Champaign county. It is probably one great mass of limestone in the central part, with several detached portions to the north and to the south of the main body. Much of it, especially the upper layers of the Columbus and the entire Delaware (?) formation, appears sandy, hard and compact. The Olentangy shale is wanting. It is quite probable that this outcrop was once a part of the belt through the central portion of the state, that it represents deposits near the old shore line, and that it has since been isolated by preglacial and glacial erosion.

In the northwestern part of the state, and beyond the anticline, lies a somewhat crescent-shaped area of outcrop with a maximum width of about twelve miles. Beginning at the Michigan-Ohio line in Lucas county, it sweeps around to the Ohio-Indiana line near Antwerp, Paulding county. The rocks in this belt have a general dip to the northwest, but the glaciated surface is comparatively horizontal and so near drainage level that extensive outcrops are exceptional.

These belts of outcrop are not to be looked upon as separate, but rather as portions of a continuous shore-line, which can also be picked

[1]See Dr. Bownocker's article, *Bull. Sci. Lab. Den. Univ.*, Vol. XI, 1898, p. 13.

up at various places in Ontario, Michigan, Indiana and Kentucky, around an island or peninsula in the Devonian sea the nucleus of which was the Cincinnati anticline.

The Middle Devonian of Ohio naturally falls into three divisions, of which the lowermost is known as the Columbus limestone, the middle as the Delaware limestone and the upper as the Olentangy shale. This division is based on both lithological and faunal differences which in some respects are more apparent in the vicinity of Columbus, although not wanting in any of the belts of outcrop. The thickness of each of these three formations varies through a considerable range in different parts of the state.

The Columbus limestone presents two rather persistent lithological differences which are excellently illustrated in the outcrops along the Scioto River, and are not absent even in the northern sections. These two phases of the formation sometimes blend with each other, but occasionally localities are found where the change is abrupt and the characteristics of each portion decided.

The lower portion of the Columbus limestone consists of a rather porous massive brown limestone frequently containing a large amount of bituminous matter and very little chert, but generally having numerous cavities or pockets filled with crystals of calcite. At some places near the base it has been observed to have a pitted or honeycombed structure. It sometimes shows a strong oblique jointing and frequently few definite bedding planes. A fresh surface shows a saccharoidal appearance, but occasionally glistens with cleavage faces of calcite. There is also a tendency to a banded structure which may be seen in the blocks of most, if not all, exposures in central Ohio. This banding, frequently of a wavy appearance, seems to be due to the presence of finely divided bituminous matter. The fossils, except in the extreme upper and lower parts, are poorly preserved and rather rare in most localities. Chemically the limestone from this part of the formation is found to be high in its percentage of magnesium. A sample from Dublin yielded forty-one and seven hundredths per cent. of magnesium carbonate,[1] while several from Bellefontaine gave even a higher percentage for this constituent.[2]

The upper part of the Columbus limestone, which includes about two-thirds of the formation, consists, in the main, of light gray limestone in even beds varying from a few inches to several feet in thickness. At places it contains a considerable amount of white or light gray fossiliferous chert, which is mainly restricted to a few zones, where it occurs in concretionary masses which are arranged in somewhat definite layers. The upper layers of the limestone are the thinner and often of a bluish color. The heavy beds, where long exposed, weather into rather thin

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[1]*Geol. Surv. Ohio*, Vol. III, 1878, pp. 615, 616.
[2]*Geol. Surv. Ohio*. 4th Ser., Bull. No. 4, 1906, p. 90, Samples 37-39.

irregular layers which break into angular blocks and fall to the base of the cliff, forming the usual talus slope. This portion of the formation always shows a crystalline or sub-crystalline structure. It is high in its percentage of calcium carbonate, which ranges from eighty-one and fourteen hundredths to ninety-three and twenty-eight hundredths per cent. in samples taken from Marble Cliff quarries.[1] While all layers seem to contain abundant fossils, many are literally crowded with the remains of the various species which swarmed in the waters of this warm Devonian sea.

The base of the Columbus limestone rests upon the Monroe formation; this contact being that between the two great systems, the Silurian and the Devonian. There is thus a great time gap or unconformity, between these two formations, which is strikingly illustrated by the decided change in character and abundance of animal remains. In some localities the lowest layers of the Columbus contain an abundant fauna which in many respects resembles that of the upper part of the same formation, but where these lower layers have been observed in Franklin, Delaware and Union counties, a basal conglomerate is found which consists of large and small water-worn pebbles of the underlying formation embedded in a matrix of Columbus limestone. Where this conglomerate is developed few fossils are found; probably because the organic remains, which existed in these localities at the time the layers in question were being deposited, were ground to a shapeless mud by the continuous action of the waves among the pebbles of a rocky coast. This conglomerate was formerly supposed to represent the Oriskany sandstone of New York, and was so mapped by the geologists who made the first county reports, as well as by Newberry himself;[2] but, since this basal conglomerate is not continuous and has not been proven to be Oriskany, it has been customary of later years, and perhaps wisely, to drop the Oriskany sandstone from the Ohio scale and include these deposits with the Columbus limestone to which they are at least very closely related.

The upper limit of the Columbus is no less interesting since it terminates in the famous "bone-bed" first described by Orton.[3] This layer or bed comprises the upper six or eight inches of the formation, and is frequently made up of an "assemblage of millions on millions of generally imperfect but mostly recognizable organs or fragments of the bony structure of the forms of fish life most characteristic of the Devonian age."[4] These teeth and dermal plates are often in an excellent state of preservation, retaining even their original luster. Contrary to what has usually been supposed, this limiting layer of the formation may be traced

[1]*Geol. Surv. Ohio*, Vol. III, 1878, p. 617; also *Geol. Surv. Ohio*, 4th Ser., Bull. No. 4, 1906, pp. 64, 65.
[2]*Geol. Surv. Ohio*, Rept. Prog. for 1869, (1870), Map opp. title page.
[3]*Geog. Surv. Ohio*, Vol. III, 1878, pp. 610, 611 and 628.
[4]Newberry, J. S., *Mong. U. S. Geol. Surv.*, Vol. XVI, 1889, p. 30

northward to Sandusky, where it has proved of invaluable assistance in determining the line of division between the Columbus and Delaware limestones.[1]

The Delaware limestone extends from the "bone-bed" upward through a thickness of about thirty-six feet to its contact with the Olentangy shale. It is extremely variable in its appearance, consisting sometimes of thin shaly layers, beds of chert and fairly massive limestone and again almost entirely of rather massive limestone with very little chert and no shale. Usually it has a deep blue to slate-color, which becomes brown on weathering. The chert, which it contains, is mostly black and non-fossiliferous, but, in sections where little occurs, it is often a light bluish-white or even pure white and somewhat fossiliferous. In general the Delaware limestone is less fossiliferous than the upper part of the Columbus, but its fauna is by no means small, and frequently layers are found which are very fossiliferous. The variable chemical composition of this formation is easily seen by a reference to the analyses of various samples collected at different localities.[2]

The Olentangy shale extends from the top of the Delaware limestone to the base of the Ohio shale, a vertical distance of about thirty-one feet in Franklin county. It has been found to be almost invariably present in the central strip from Sandusky southward. In Pickaway county, where the Devonian limestones last appear, this shale occurs, and from thence southward overlaps on the older rocks until at Bainbridge it rests on Niagaran limestones. The Devonian shales cross the Ohio River at Vanceburg, and even near Fox Springs, Fleming county, Kentucky, the basal shale has the appearance of the Olentangy.[3] As seen in the river bank at Delaware, the Olentangy is a soft bluish shale, with numerous disc-like argillaceous limestone concretions near the basal portion, and layers of impure limestone in the middle and upper portions. (See Plate XII). The formation contains few fossils in central Ohio, but becomes quite fossiliferous in the Sandusky region, where it includes a limestone member, at the top, which has been known as the Prout limestone. The thickness of the formation is there also greatly increased.

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[1] *Jour. Geol.* ,Vol. XIII, No. 5, 1905, p. 435.

[2] *Rept. Geol. Surv. Ohio*, Vol. III, 1878, pp. 617, 618; also *Geol. Surv. Ohio*, 4th Ser., Bull. No. 4, 1906, pp. 61, 65, 95, 125, etc.

[3] Morse, W. C., Private communication, 1908.

CHAPTER II.

DISCUSSION OF SECTIONS AND FAUNAS.

GENERAL SECTION FOR CENTRAL OHIO.

During the progress of the field work in connection with the development of this subject, all measurements, where possible, were made from the two well fixed boundaries of the Columbus limestone, its contact with the Monroe formation and the "bone-bed." Other persistent and apparently fixed characteristics have been observed. Of these the most important are the horizons at which certain faunas occur and the zonal character of the chert beds. A comparison of various sections from central Ohio, after the identification of the species from the collection of each, shows that certain groups of species usually occur in the same relation to each other and at relatively the same positions in the section. This has led to the arrangement of a general section, to which others may be referred, in which the formations are divided into zones, each of which has some faunal or lithological feature or both, which seems to be characteristic of it. This section does not agree in all of its particulars with that found farther north, and yet there are some things in common.

Of course it is not to be supposed that the lines of division between these zones are definite and sharp, although sometimes that is the case, nor that a form persistently occurring in one may not occur in another. *Hadrophyllum d'orbignyi*, which has been found constant enough in the Delaware limestone to be considered as forming a thin zone, also occurs in the "bone-bed" and slabs of limestone from this last named horizon, have been collected near Columbus, in which this Coral is imbedded in great numbers, but it cannot be traced from section to section over an extended area as it can in its later occurrence. *Tentaculites scalariformis* may be found throughout the whole of the Delaware limestone and sometimes in great numbers, as far down into the Columbus limestone as the middle of the chert zone, but its greatest abundance has been found some eight or ten feet above the base of the Delaware. *Spirifer acuminatus* occurs throughout a small range in the southern part of the central area, and seems to have essentially the same zone in Indiana,[1] but at Sandusky it is found in abundance at several horizons below that

[1] *Bull. Am. Pal. No. 12*, 1899, p. 110; also 25th Ann. Rept. *Dept. Geol. and Nat. Res. of Ind.*, 1900, p. 538.

mentioned in the general section. *Spirifer gregarius* also has an extensive range through the Columbus, but what is called the "*Sp. gregarius* zone" is found to contain this fossil in large numbers, sometimes fairly crowding each other in the layers. And so others might be pointed out, but where the species is mentioned as characteristic of a zone, it is believed to occur in its greatest abundance, and as a rule these divisions are quite easily recognized.

GENERAL SECTION OF THE MIDDLE DEVONIAN OF CENTRAL OHIO.

Ohio shale.

Olentangy shale.

Feet.

Soft blue shale with layers of impure blue limestone. Fossils rare in central Ohio but becoming plentiful in the north, where several distinct zones may be distinguished 31

Delaware limestone.

(Zone M) Grayish or bluish brown limestone in layers of about six inches and containing some fossiliferous chert. This is the horizon which Winchell called "Tully limestone" and which Newberry conceded to contain a Hamilton fauna. Average thickness.... 10

Common fauna of this zone.

Aulopora conferta Winchell
Aviculopecten princeps (Conrad)
Nyassa arguta Hall
Ambocœlia umbonata (Conrad)
Atrypa reticularis (Linnaeus)
Camarotœchia prolifica (Hall)
Chonetes mucronatus (Hall)
Pholidostrophia iowaensis (Owen)
Rhipidomella vanuxemi Hall
Stropheodonta concava Hall
Stropheodonta perplana (Conrad)
Stropheodonta demissa (Conrad)

Feet.

(Zone L) Granular grayish brown limestone, frequently made up to a large extent of the globular Coral, *Hadrophyllum d'orbignyi.* It also contains many Brachiopods and occasionally abundant fish teeth. Iron pyrites often replaces the substance of the fossils. Average thickness..... ¼

Common fauna of this zone.

Hadrophyllum d'orbignyi Edwards and Haime
Cystodictya gilberti (Meek)
Fistulipora vesiculata (Hall and Simpson)
Trematella arborea (?) (Hall)
Atrypa reticularis (Linnaeus)
Camarotœchia tethys (Billings)
Chonetes mucronatus Hall
Chonostrophia reversa (Whitfield)
Delthyris consobrina (d'Orbigny)
Eunella lincklæni Hall
Pholidostrophia iowaensis (Owen)
Rhipidomella vanuxemi Hall
Spirifer audaculus mucronatus Hall
Spirifer macrus Hall
Stropheodonta concava Hall
Stropheodonta demissa (Conrad)
Stropheodonta hemispherica Hall
Stropheodonta perplana (Conrad)
Conocardium sp.

Feet.

(Zone K) Frequently containing much black chert and Occasionally fairly massive layers of blue or brown limestone alternating with thin cherty layers. At the base it is often more or less contorted. *Grammysia bisulcata* is a common fossil. Average thickness.... 11

Common fauna of this zone.

Cystodictya gilberti (Meek)
Camarotœchia billingsi Hall
Camarotœchia tethys (Billings)
Chonetes mucronatus Hall
Leptæna rhomboidalis (Wilckens)
Rhipidomella vanuxemi Hall
Spirifer audaculus macronotus Hall
Stropheodonta demissa (Conrad)
Glyptodesma erectum (Conrad)
Grammysia bisulcata (Conrad)
Grammysia arcuata Whitfield

Feet

(Zone J) Usually a massive blue limestone with some thin or shaly layers and occasionally much black chert. It contains a great abundance of *Tentaculites scalariformis.* Average thickness..... 9

Common fauna of this zone.

Fenestella parallela (?) Hall
Ambocœlia umbonata (Conrad)
Chonetes mucronatus Hall

Chonetes scitulus Hall
Chonostrophia reversa (Whitfield)
Delthyris consobrina (d'Orbigny)
Leiorhynchus limitare (Vanuxemi)
Leptæna rhomboidalis (Wilckens)
Lingula ligea Hall
Orbiculoidea lodiensis (Vanuxem)
Rhipidomella vanuxemi Hall
Spirifer macrus Hall
Stropheodonta demissa (Conrad)
Glyptodesma erectum (Conrad)
Platyceras erectum Hall
Tentaculites scalariformis Hall

	Feet.
(Zone I) Brown to bluish shale or thin-bedded shaly limestone with some black chert. To the north it becomes massive, but seems to retain its distinctive fauna of *Leiorhynchus limitare, Lingula manni, Orbiculoidea lodiensis,* etc. This is Whitfield's Marcellus shale. Average thickness.....	6

Common fauna of this zone. In the shaly layers are found:

Chonostrophia reversa (Whitfield)
Delthyris consobrina (d'Orbigny)
Leiorhynchus limitare (Vanuxem)
Leptaena rhomboidalis (Wilckens)
Lingula manni Hall
Martinia maia (Billings)
Orbiculoidea lodiensis (Vanuxem)
Orbiculoidea minuta (Hall)
Tentaculites scalariformis Hall

And in addition to this fauna, as these layers pass into thick bedded limestone to the north, may be found:

Cystodictya gilberti (Meek)
Orthopora regularis Hall
Camarotœchia billingsi Hall
Camarotœchia tethys (Billings)
Chonetes mucronatus Hall
Productella spinulicosta Hall
Spirifer macrus Hall.
Stropheodonta concava Hall
Macrodon sp.
Paracyclas elliptica Hall
Sphenotus cuneatus (Conrad)
Platyceras erectum (Hall)

Columbus limestone.

Feet.

(Zone H) Thin bedded to massive bluish gray limestone. At the top it contains the "bone-bed," which has a thickness varying from several inches to a foot or more and is made up to a greater or less extent of the teeth, bones and dermal plates of fish. It also contains some fossiliferous gray chert which often occurs in layers. The zone contains many fossils, among which are especially to be mentioned, *Spirifer acuminatus, Nucleocrinus verneuili, Spirifer duodenarius, Paracyclas elliptica, Diphyphyllum verneuilanum.* Average thickness..... 10

Common fauna of this zone.

Cyathophyllum robustum Hall
Diphyphyllum verneuilanum (Edwards and Haime)
Favosites emmonsi Rominger
Favosites hemisphericus (Troost)
Codaster pyramidatus Shumard
Nucleocrinus verneuili (Troost)
Cystodictya gilberti (Meek)
Atrypa reticularis (Linnaeus)
Atrypa spinosa Hall
Chonetes mucronatus Hall
Camarotœchia tethys (Billings)
Eunella lincklæni Hall
Leptæna rhomboidalis (Wilckens)
Pentamerella arata (Conrad)
Pholidostrophia iowaensis (Owen)
Schizophoria propinque Hall
Spirifer acuminatus (Conrad)
Spirifer duodenarius (Hall)
Spirifer macrus Hall
Stropheodonta concava Hall
Stropheodonta hemispherica Hall
Stropheodonta inæquistriata (Conrad)
Stropheodonta perplana (Conrad)
Aviculopecten cleon Hall
Aviculopecten princeps (Conrad)
Loxonema pexatum Hall
Platyceras dumosum Conrad
Platyceras multispinosum Meek
Tentaculites scalariformis Hall
Chasmops calypso Hall
Odontocephalus bifidus (?) Hall
Phacops cristata Hall

Feet.

(Zone G) Massive gray limestone in beds from eight inches to three feet in thickness. Very fossiliferous and characterized by the occurrence in it of such large Cephalopods as *Gyroceras cyclops, Gyroceras Columbiense,* etc. Average thickness..... 22

Common fauna of this zone.

Calcisphæra robusta Williamson
Stromatopora ponderosa Nicholson
Zaphrentis cornicula (Edwards and Haime)
Atrypa reticularis (Linnæus)
Atrypa spinosa Hall
Chonetes mucronatus Hall
Delthyris raricosta Conrad
Spirifer gregarius Clapp
Spirifer macrus Hall
Stropheodonta hemispherica Hall
Stropheodonta inæquistriata (Conrad)
Stropheodonta perplana (Conrad)
Conocardium cuneus (Conrad)
Limoptera pauperata (?) Hall
Paracylas elliptica Hall
Callonema lichas (Hall)
Euomphalus decewi Billings
Loxonema pexatum Hall
Pleurotomaria lucina Hall
Turbo shumardi (Verneuil)
Gyroceras columbiense Whitfield
Gyroceras cyclops Hall
Coronura diurus (Green)

Feet.

(Zone F) Massive gray limestone containing numerous fossils, but *Spirifer gregarius* exceedingly abundant, and usually referred to as the *Sp. gregarius* zone. Average thickness 5

Common fauna of this zone.

Zaphrentis cornicula (Edwards and Haime)
Zaphrentis gigantea Rafinesque
Atrypa reticularis (Linnæus)
Atrypa spinosa Hall
Chonetes mucronatus Hall
Eunella lincklæni Hall
Nucleospira concinna Hall
Pholidostrophia iowaensis (Owen)
Spirifer divaricatus Hall
Spirifer gregarius Clapp
Spirifer macrus Hall
Stropheodonta hemispherica Hall
Stropheodonta inæquistriata (Conrad)
Stropheodonta perplana (Conrad)
Conocardium cuneus (Conrad)
Modimorpha concentrica (Conrad)
Paracyclas elliptica Hall
Bellerophon pelops Hall
Callonema lichas (Hall)
Murchisonia desiderata var. Hall
Platyceras dumosum Conrad
Coleolus crenatocinctus Hall
Phacops cristata Hall

4—S. G.—1,000.

Feet.

(Zone E) Massive gray limestone with an abundant fauna, but *Spirifer macrothyris* and *Strophonella ampla* are especially abundant. Average thickness..... 20

Common fauna of this zone.

Stromatopora ponderosa Nicholson
Favosites emmonsi Rominger
Favosites hemisphericus (Troost)
Syringopora tabulata Edwards and Haime
Zaphrentis gigantea Rafinesque
Athyris vittata indianaensis n. var.
Atrypa reticularis (Linnæus)
Chonetes mucronatus Hall
Delthyris raricosta Conrad
Eunella lincklæni Hall
Leptæna rhomboidalis (Wilckens)
Meristella nasuta (Conrad)
Nucleospira concinna Hall
Productella spinulicosta Hall
Schizophoria propinque Hall
Spirifer divaricatus Hall
Spirifer gregarius Clapp
Spirifer macrothyris Hall
Spirifer macrus Hall
Spirifer manni Hall
Stropheodonta hemispherica Hall
Stropheodonta inæquistriata (Conrad)
Stropheodonta patersoni Hall
Stropheodonta perplana (Conrad)
Strophonella ampla Hall
Conocardium cuneus (Conrad)
Modiomorpha concentrica (Conrad)
Mytilarca percarinata Whitfield
Paracyclas elliptica Hall
Plethomytilus ponderosa Hall
Bellerophon pelops Hall
Callonema lichas Hall
Euomphalus decewi Billings
Loxonema pexatum Hall
Palæotrochus kearneyi Hall
Platyceras attenuatum Hall
Platyceras carinatum Hall
Platyceras dumosum (?) Conrad
Pleurotomaria lucina Hall
Turbo shumardi Verneuil
Coleolus crenatocinctus Hall
Tentaculites scalariformis Hall
Gyroceratites ohioensis Meek
Orthoceras ohioense Meek
Orthoceras thoas Hall
Coronura diurus (Green)
Phacops cristata Hall

Feet.

(Zone D) Layers of gray chert alternating with layers of a sub-crystalline gray or brown limestone. Chert hard to chalky and very fossiliferous, containing a great variety of Gastropods and many Brachiopods, Pelecypods, Corals and Bryozoa. The fossils usually have their exterior markings excellently preserved. This is the chert or Gastropod zone. Average thickness..... 8

Common fauna of this zone.

Stromatopora ponderosa Nicholson
Syringostroma columnaris Nicholson
Favosites emmonsi Rominger
Favosites hemisphericus (Troost)
Zaphrentis sp.
Coscinium striatum Hall and Simpson
Fenestella parallela Hall
Lichenalia sp.
Nemataxis fibrosus Hall
Polypora celsipora (Hall)
Polypora flabelliformis (?) (Hall)
Polypora hexagonalis (Hall)
Polypora robusta (Hall)
Prismopora triquetra Hall
Semicoscinium bi-imbricata (Hall)
Stictopora sp.
Unitrypa tegulata (Hall)
Atrypa reticularis (Linnæus)
Atrypa spinosa (?) Hall
Camarotœchia tethys (Billings)
Chonetes mucronatus Hall
Crania sp.
Eunella lincklæni Hall
Meristella nasuta (Conrad)
Nucleospira concinna Hall
Pholidostrophia iowaensis (Owen)
Productella spinulicosta Hall
Rhipidomella vanuxemi Hall
Spirifer divaricatus Hall
Spirifer macrus Hall
Spirifer manni Hall
Stropheodonta demissa (?) (Conrad)
Stropheodonta hemispherica Hall
Stropheodonta inæquistriata (Conrad)
Stropheodonta perplana (Conrad)
Strophonella ampla Hall
Conocardium cuneus (Conrad)
Conocardium cuneus attenuate Conrad
Conocardium cuneus trigonale Hall
Goniophora sp.
Grammysia subarcuata (?) Hall

Modiomorpha concentrica (Conrad)
Mytilarca percarinata Whitfield
Nucula niotica Hall and Whitfield
Nucula sp.
Paracyclas ohioensis Meek
Plethomytilus ponderosa Hall
Schizodus contractus Hall
Schizodus tumidus Hall
Bellerophon hyalina Hall
Bellerophon newberryi Meek
Bellerophon pelops Hall
Bellerophon sp.
Callonema bellatulum (Hall)
Callonema clarki Nettelroth
Callonema lichas (Hall)
Cyclonema crenulatum Meek
Dentalium martini Whitfield
Isonema depressum Meek and Worthen
Isonema humile Meek
Loxonema læviusculum Hall
Loxonema pexatum Hall
Loxonema robustum Hall
Loxonema sp.
Macrochilina hebe (?) (Hall)
Macrochilina macrostoma (Hall)
Macrochilina prisca (Whitfield)
Murchisonia desiderata Hall
Murchisonia maia Hall
Naticopsis æquistriata Meek
Naticopsis comperta Hall
Naticopsis lævis Meek
Orthonema newberryi Meek
Platyceras bucculentum Hall
Pleurotomaria adjutor Hall
Pleurotomaria hyphantes Meek
Pleurotomaria lucina Hall
Pleurotomaria plena Hall
Pleurotomaria sp.
Pseudophorus antiquus Meek
Strophostylas varians Hall
Coleolus crenatocinctus Hall
Gyroceras columbiense Whitfield
Orthoceras cretaceum Whitfield
Orthoceras nuntium Hall
Orthoceras ohioense Hall
Orthoceras sirpus Hall
Orthoceras thoas Hall
Phacops cristata Hall

Feet.

(Zone C) Brown limestone, quite massive, with numerous Corals imbedded in it. At places it becomes a true fossil Coral reef. Usually called the Coral zone. Average thickness..... 4

Common fauna of this zone.

Stromatopora ponderosa Nicholson
Cladopora pulchra Rominger
Cladopora robusta Rominger
Diphyphyllum simcoense (Billings)
Diphyphyllum strictum (Edwards and Haime)
Favosites emmonsi Rominger
Favosites goldfussi d'Orbigny
Favosites hemisphericus (Troost)
Syringopora tabulata Edwards and Haime
Zaphrentis gigantea Rafinesque
Atrypa reticularis (Linnæus)
Camarotœchia tethys (Billings)
Chonetes mucronatus Hall
Eunella lincklæni Hall
Meristella rostrata (?) Hall
Reticularia fimbriata (Conrad)
Spirifer macrothyris Hall
Spirifer macrus Hall
Stropheodonta hemispherica Hall
Stropheodonta inæquistriata (Conrad)
Actinopteria sp.
Aviculopecten cleon Hall
Paracyclas elliptica (?) Hall

Feet.

(Zone B) Brown limestone, exceedingly massive, showing but few irregular bedding planes, and at places appearing as a solid wall without bedding planes. It contains much bituminous matter, has a saccharoidal appearance, and often shows a slightly banded structure. The fresh surface of the rock sometimes glistens with cleavage faces of calcite and frequently contains pockets of the crystals. It also contains more or less chert scattered through the upper part. Fossils are usually rare and poorly preserved. Average thickness 35

Common fauna of this zone.

Cladopora pulchra Rominger
Diphyphyllum simcoense (Billings)
Syringopora tabulata Edwards and Haime
Zaphrentis gigantea Rafinesque
Fenestella erectipora (?) Hall
Fenestella sp.
Fistulipora substellata (?) Hall
Nemataxis fibrosus Hall
Camarotœchia billingsi Hall
Meristella nasuta (Conrad)
Spirifer macrus Hall
Stropheodonta demissa (?) (Conrad)
Stropheodonta hemispherica Hall
Strophonella ampla Hall
Conocardium cuneus (Conrad)
Pleurotomaria sp.

	Feet.
(Zone A) Usually a conglomerate composed of water-worn pebbles of Monroe limestone imbedded in a matrix of brown Columbus limestone. Fragments of fossils are occasionally found, but northward the conglomerate ceases and the zone becomes very fossiliferous. Average thickness.....	1

Monroe limestone.

SECTIONS AND FAUNAS OF THE CENTRAL DISTRICT.

The rock sections of the southern part of the state show only the upper formation, the Olentangy shale, of the Middle Devonian, and even that is sometimes wanting. In the vicinity of Buena Vista, Scioto county, J. E. Hyde found a considerable thickness of soft gray shales alternating with black shales forming the base of the section, although the underlying limestone was not exposed at the place observed. At Mineral Springs station, Adams county, however, the underlying limestone was found, and above it occurs "about six inches of black fissile shale" which is succeeded by a slight covered interval, and then follows "five feet (estimated) of very light gray, almost white, clay shale very like the Olentangy;"[1] and this is succeeded by black shales with another gray band higher up. Perhaps this is the Olentangy shale, but at Kinkead Springs, one mile west of Latham, Pike county, the black shale extends down to the limestone, and is firmly welded to it.

Bainbridge.—In the gulleys leading down from Benner's Hill,[2] on the east side of Buckskin Run, a tributary to Paint Creek and about two miles north of Bainbridge, Ross county, are excellent sections from the Silurian well up into the Mississippian. The base of the section is formed by the Niagaran and Cayugan limestones above which follows immediately about thirty feet of the Olentangy shale. Near the bottom of this blue shale are two layers of purple shale, marked with trails of the light blue, as in the sections of central Ohio. There are also a few layers of brown shale, in which an occasional specimen of *Lingula* occurs, interstratified with the blue layers, and near the top of the formation the flat disc-like blue limestone concretions, so characteristic of the formation at the type locality, are to be found. Above the Olentangy shale comes the regular central Ohio section up to and including the Cuyahoga formation. The notable feature here, as at all of the other Ohio localities to the south, is the absence of the Middle Devonian limestones. This indicates a transgression of the sea along the southeastern portion of the

[1]Hyde, J. E., letter of September 24th, 1909.
[2]See Orton, Edward, *Geol. Surv. Ohio*, Vol. II, 1874, pp. 645, 646; also Prosser, Charles S., *Jour. Geol.*, Vol. X, 1902, pp. 278-282.

Cincinnati Island from Deer Creek, Pickaway county, where the last of the limestones outcrop, southward into Kentucky, during Olentangy time.

Deer Creek.—Along Deer Creek in Pickaway county there are several Devonian limestone outcrops, from which the stone was once quarried and burned for lime. These old lime-kilns have long since tumbled down, and even the quarries are more or less covered by the caving of the soil and mantle rock. A representative of these[1] may be found on the farm belonging to Mr. Thomas, and lying on the north side of the creek five and one-half miles northwest of Williamsport and four miles north of Atlanta. The old kiln, where the following section may be found, was located in a ravine entering Deer Creek from the north about one-half mile east of the mill.

Columbus limestone.

	Ft.	In.
3. Crystalline gray limestone, quite fossiliferous and partly covered	5	4
2. Conglomerate made up of water-lime pebbles imbedded in Columbus limestone, all well exposed	1	0

Monroe limestone.

1. Compact banded drab limestone	3	0

From number three of the above section, the following species were collected:

Favosites emmonsi Rominger
Favosites hemisphericus (Troost)
Meristella nasuta (Conrad)
Stropheodonta demissa (Conrad)
Stropheodonta hemispherica Hall
Conocardium cuneus (Conrad)

On the south side of the creek opposite the above section are other outcrops. A well dug on the hill just above is said to have struck limestone at a depth of fifty-six feet. Immediately above the limestone the man who dug the well reports the occurrence of a "blue soapstone clay twenty feet deep, which is in distinct layers, has no grit and could be spaded out like clay"—probably the Olentangy shale.

The presence of the basal conglomerate indicates shore conditions at the beginning of the Devonian, but whether or not the limestones

[1]See also Bownocker, J. A., *Bull. Sci., Lab. Den. Univ.*, Vol. XI, 1898, pp. 17, 18.

have appreciably thinned out at this point is somewhat uncertain. The section just given seems to indicate the disappearance of the lower or brown dolomitic portion of the Columbus limestone, and the probable presence of the Olentangy shale at such a short interval above the Monroe formation, points to a lessening of the distance between these two formations.

Andrews states that the Devonian limestones occur "in the northwestern corner of Ross county,"[1] but an examination of the outcrops of that locality failed to reveal anything but Monroe limestone.

Harrisburg.—This town lies fifteen miles southwest of Columbus, and at the point where the Big Darby crosses the Franklin-Pickaway county line. The creek flows over rock above the lower highway bridge, and indeed the whole of this part of the valley is but a few feet above the rock, as is shown by the holes dug in setting telephone poles and by the numerous small outcrops along the road from Morgan. The most important exposed section is west of the creek at the old lime-kiln by the flowing wells. Here in a small quarry at the foot of the hills, the rock has been removed to a depth of perhaps ten feet, and its character excellently shown although the section itself is rather unsatisfactory. The limestone has a gray color, is fairly massive and abounds in fossils. This is especially true of some layers which are made up almost entirely of the remains of Brachiopods.[2] In the course of several hours the following species were collected from the loose material around the kiln:

Cystiphyllum vesiculosum Goldfuss
Favosites emmonsi Rominger
Syringopora tabulata Edwards and Haime
Zaphrentis cornicula Edwards and Haime
Atrypa reticularis (Linnæus)
Chonetes mucronatus Hall
Camarotœchia billingsi Hall
Meristella nasuta (Conrad)
Rhipidomella cleobis Hall
Rhipidomella vanuxemi Hall
Schizophoria propinque Hall
Spirifer divaricatus Hall
Spirifer gregarius Clapp
Spirifer macrothyris Hall
Spirifer macrus Hall
Stropheodonta concava Hall
Stropheodonta demissa (Conrad)
Stropheodonta inæquiradiata (Conrad)
Strophonella ampla Hall
Conocardium cuneus (Conrad)
Modiomorpha concentrica (Conrad)

[1]*Geol. Surv. Ohio*, Vol. II, pt. 1, 1874, p. 592.
[2]See *Bull. Sci. Lab. Den. Univ.*, Vol. XI, 1898, p. 20.

Pterinea flabellum (Conrad)
Schizodus tumidus Hall
Bellerophon pelops Hall
Callomena lichas (Hall)
Euomphalus decewi Billings
Loxonema pexatum Hall
Loxonema sp.
Platyceras dumosum Conrad
Pleurotomaria lucina Hall
Turbo shumardi Verneuil
Tentaculites scalariformis Hall
Orthoceras sp.
Coronura diurus (Green)
Odontocephalus bifidus Hall
Phacops cristata Hall

It seems quite probable that this outcrop lies from forty to fifty feet below the "bone-bed" or top of the Columbus limestone, since the above fauna is that of Zone E in the general section.

Georgesville.—In the vicinity of Georgesville at the junction of the Big and Little Darby Creeks, about seven miles northwest of Harrisburg, and on the Big Four Railroad thirteen miles southwest of Columbus, the base of the Columbus limestone is shown with the underlying Monroe formation. Perhaps the best exposure is the cliff about a half-mile above the dam across the Little Darby and where the creek makes a sharp turn from a southerly to an easterly direction on Mr. E. N. Coberly's farm. Here the following section may be seen.

Columbus limestone.

	Ft.	In.
Brownish gray crystalline limestone, honeycombed, containing crystals of calcite, overhanging the formation below and most of the exposed surfaces stained red by iron oxides. A few fragments of fossils seen	14	5

Monroe limestone.

Thin bedded drab limestone, having a laminated structure and very compact. Partly covered near the creek	18	6

The upper layers of the Monroe limestone show some signs of weathering, but there seems to be no conglomerate developed in the base of the Columbus limestone at this particular place, although on the west

bank of the Big Darby, two miles above Georgesville, just north of the cottages on the A., C. and M. Eckles farm, it is nicely shown in an old quarry, of which the following is a section.

Columbus limestone.

		Ft.	In.
5.	Massive brown limestone containing a few Corals of the genus *Favosites;* and cavities, some of which are quite large, filled with crystals of calcite	10	4
4.	Conglomerate composed of large rounded pebbles of compact drab limestone imbedded in brown limestone	0	8
3.	Brownish limestone containing a few small pebbles	0	7

Monroe limestone.

2.	Massive drab limestone containing *Leperditia alta*	1	10
1.	Partly covered with blocks thrown from the quarry, to creek level	1	8

The following species were found in No. 5 of the above section:

Favosites emmonsi Rominger
Favosites goldfussi d'Orbigny
Favosites hemisphericus (Troost)
Favosites maximus (Troost)
Favosites sp.
Zaphrentis gigantea Rafinesque
Zaphrentis prolifica Billings
Zaphrentis sp.
Fenestella sp.
Atrypa spinosa Hall
Stropheodonta demissa (Conrad)
Stropheodonta hemispherica Hall

The base of the Columbus limestone is again shown on the east bank of the Little Darby, three and one-half miles above Georgesville and near the old lime-kiln just below Mr. Charles Roberts' house, as well as in an old quarry in the field northeast of his barn. The section is mostly in the Monroe formation, but the conglomerate at the base of the Devonian may be seen near the top. It presents no new features and possesses interest solely because of the important contact which is here exposed. No fossils were seen in this locality.

The banks of the Scioto and its tributaries from Columbus northward to near Warrensburg, furnish many and interesting sections. No

single outcrop gives the whole of the Columbus limestone, yet within a very few miles both contacts may be seen, and by combining the sections at these places a fair idea of the formation may be obtained. However, it is not a safe conclusion to assume that the true thickness of the Columbus limestone is thus obtained, even though zones which are considered equivalent are found at both places.

Columbus.—Just outside of the city limits, and near the State Hospital for the Insane, lie the State Quarries.[1] The importance of this section has deteriorated much, within the past score of years, from the fact that the quarries have been practically abandoned, and are thus in a state of ruin. But as many fine collections have been obtained and some new species described from this historic ground, it is safe to assume that a geological interest will be attached to it for years to come. The following section was measured just south of the Big Four Railroad tracks, where a fair section may still be seen.

Delaware limestone.

		Ft.	In.
10.	Zone I. Thin shaly brown limestone alternating with irregular layers of black chert	3	0

Columbus limestone.

9.	Zone H. Massive fossiliferous gray limestone containing the "bone-bed" at the top	1	0
8.	Fossiliferous grayish white chert	0	3
7.	Massive Crinoidal gray limestone	3	0
6.	Fossiliferous light gray chert	0	3
5.	Massive gray limestone	2	0
4.	Fossiliferous light gray chert	0	2
3.	Massive gray limestone	1	4
2.	"Smooth layer"	..	..
1.	Zone G. Massive gray limestone, very fossiliferous, especially containing a large number of cup Corals. No chert	12	0

The term "smooth layer" or "smooth rock," number two of the above section, was probably introduced by Orton.[2] It has the appearance of a plane, sometimes undulating, along which lateral motion has occurred. The rock both above and below the plane is smoothed and fossils occurring in its path have been sheared off. It can be traced northward beyond Dublin, still retaining its distance of eight to ten feet below the "bone-bed."

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[1]*Geol. Surv. Ohio*, Vol. III, 1878, pp. 612-614.
[2]Orton, Edward, *Geol. Surv. Ohio*, Vol. III, 1878, pp. 608-610.

The following small collection of species was made from the upper part (Zone H) of the Columbus limestone:

Diphyphyllum verneuilanum (Edwards and Haime)
Zaphrentis cornicula Edwards and Haime
Zaphrentis gigantea Rafinesque
Zaphrentis wortheni Nicholson
Codaster pyramidatus Shumard
Nucleocrinus verneuili (Troost)
Fenestella parallela Hall
Fenestella sp.
Polypora celsipora minima (?) Hall
Atrypa reticularis (Linnæus)
Chonetes mucronatus Hall
Cyrtina hamiltonensis Hall
Eunella lincklæni Hall
Nucleospira concinna Hall
Pholidostrophia iowaensis (Owen)
Reticularia fimbriata (Conrad)
Schizophoria propinque Hall
Spirifer acuminatus Conrad
Spirifer duodenarius (Hall)
Spirifer sp.
Stropheodonta hemispherica Hall
Stropheodonta inæquiradiata Hall
Stropheodonta perplana (Conrad)
Aviculopecten cleon Hall
Platyceras dumosum Conrad
Platyceras multispinosum Meek
Tentaculites scalariformis Hall
Orthoceras sp.
Phacops cristata Hall

Marble Cliff.—On Fifth avenue, three and one-half miles west from High street, is the railway station known as Marble Cliff. In its immediate vicinity there are quite a number of large quarries, with similar sections, but none of them passing through the entire Columbus limestone.

The Smith and Price quarry is the old pit located on the east bank of the Scioto and just above the Pennsylvania Railroad bridge. The contact between the Columbus and Delaware limestones is excellently shown here, as is also the case in the neighboring quarries.

	Ft.	In.
8. Drift	4	0

Delaware limestone.

	Ft.	In.
7. Zone J. Thin bedded brown limestone containing several layers of black chert and cherty limestone	9	10
6. Zone I. Thin shaly brown limestone with layers of chert	4	0
5. Brown shale alternating with black chert and cherty limestone. The lower seven inches is all shale and very fossiliferous	2	0

Columbus limestone.

4. Zone H. "Bone bed"	..	..
3. Gray limestone in eight to twelve-inch layers. It contains a distinct bone bed at the top and some fish remains throughout. Two and one-half feet below the "bone-bed" occurs a three-inch layer of *Diphyphyllum verneuilanum*	9	2
2. "Smooth layer"	..	..
1. Zone G. Massive gray limestone in layers from one to three feet in thickness, to the bottom of the quarry	10	4

The following collection of species was obtained largely from the loose material at the north end of the quarry and represents, in the main, Zone I of the Delaware and Zone H of the Columbus.

Delaware limestone.

Chonostrophia reversa (Whitfield)
Leptaena rhomboidalis (Wilckens)
Martinia maia (Billings)
Orbiculoidea lodiensis (Vanuxem)
Orbiculoidea minuta (Hall)

Columbus limestone.

Diphyphyllum verneuilanum (Edwards and Haime)
Zaphrentis cornicula Edwards and Haime
Atrypa reticularis (Linnæus)
Atrypa spinosa Hall
Delthyris raricosta Conrad
Schizophoria propinque Hall
Spirifer acuminatus (Conrad)
Conocardium cuneus (Conrad)
Limopteria pauperata Hall

Callonema lichas Hall
Euomphalus decewi Billings
Loxonema pexatum Hall
Platyceras dumosum Conrad

Orton gives a section of the rocks in this quarry, in his Franklin county report,[1] and Bownocker collected his Marble Cliff fauna from this place.[2]

Just across the river and south of the Pennsylvania tracks is the quarry of the Columbus Stone Company, formerly known as the Taylor and Bell quarry. Here the limestone has been removed to a depth of fifty-one feet below the "bone-bed," thus giving an excellent idea of the upper part of the Columbus limestone. The following is a section of the rocks in this quarry:

Delaware limestone.

	Ft.	In.
8. Zone J. Thin bedded bluish-brown limestone with some layers of black chert	4	0
7. Zone I. Thin shaly limestone with some chert, becoming a true shale at the base. It shows quite regular oblique joints which extend in two directions	6	0

Columbus limestone.

6. Zone H. "Bone-bed"	..	..
5. Bluish-gray limestone in five to twelve-inch beds. It contains also several layers of fossiliferous gray chert and a persistent three-inch layer of *Diphyphyllum verneuilanum* two feet eight inches below the top of the "bone-bed"	9	2
4. "Smooth layer"	..	..
3. Zone G. Massive gray limestone in layers from one to two feet	22	10
2. Zone F. Massive gray limestone containing numerous specimens of *Spirifer gregarius*	3	0
1. Zone E. Massive gray limestone in two to three-foot layers to the bottom of the quarry	16	0

The following represents a small collection of the species found at this place:

Delaware limestone.

	Zones.
Martinia maia (Billings)	I
Orbiculoidea lodiensis (Vanuxem)	I

[1] *Geol. Surv. Ohio*, Vol. III, 1878, p. 608,
[2] *Bull. Sci. Lab. Den. Univ.*, Vol. XI, 1898, pp. 15, 16.

The south wall of the Columbus Stone Company's quarry at Marble Cliff. The illustration shows the increasing massiveness from the top downward in the Columbus limestone.

(Photo by R. F. Griggs.)

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Columbus limestone.

Stromatopora ponderosa Nicholson	G
Diphyphyllum verneuilanum (Edwards and Haime)	H
Favosites emmonsi Rominger	E
Favosites hemisphericus (Troost)	E, G
Syringopora tabulata Edwards and Haime	E
Zaphrentis gigantea Rafinesque	E
Fenestella sp.	E
Atrypa reticularis (Linnæus)	E, F, G
Chonetes mucronatus Hall	G
Leptæna rhomboidalis (Wilckens)	H
Schizophoria propinque Hall	E
Spirifer gregarius Clapp	E, F
Spirifer macrothyris Hall	E
Spirifer macrus Hall	G
Stropheodonta hemispherica Hall	E, F, G, H
Stropheodonta perplana (Conrad)	G
Strophonella ampla Hall	E
Aviculopecten princeps (Conrad)	H
Conocardium cuneus (Conrad)	E, F
Paracyclas elliptica Hall	G
Euomphalus decewi Billings	G
Loxonema pexatum Hall	E
Platyceras dumosum Conrad	H
Pleurotomaria lucina Hall	E, G
Phacops cristata Hall	H

The rock of the Columbus limestone exposed in this quarry shows its usual even bedding (See Plate VIII). These bedding planes aid materially in quarrying, the more prominent ones being used as benches. The rock also shows many oblique joints, some of which have been much widened by solution and the sides covered with crystals of calcite or a deposit of travertine. The bottom of the quarry is very near the top of the chert zone. At the west end some of the lowest blasts in the bottom of the quarry have torn up fragments of rock carrying gray chert, which has a Gastropod fauna identical with that of Zone D of the general section. The lower part of this quarry is also interesting from the fact that it has a fauna similar to and approaching in abundance of species that of Harrisburg; in fact, there can be no doubt but that the horizons are the same. Many large specimens of *Favosites emmonsi* and *Syringopora tabulata* project from the bottom course and much organic matter in the form of petroleum is included within the cavities of the fossils of this horizon.

The Casparis quarry is the largest of the Marble Cliff group. It is located about a half-mile up the river from the Pennsylvania station, and occupies the banks on both sides of the Scioto. However, the section,

except that of the Delaware limestone, is not so great as at the preceding place. The following section was measured on the east side of the river:

Delaware limestone.

		Ft.	In.
12.	Zone K. Rather thin bedded bluish brown limestone containing some chert in the upper part and all much weathered	5	0
11.	Zone J. Thin bedded bluish limestone containing a large amount of black chert in layers	5	10
10.	Massive bluish limestone with much black chert intermixed. The upper part is often more or less concretionary in appearance	3	8
9.	Zone I. Shaly and rather thick layers of bluish brown limestone containing much black chert	5	0
8.	Soft thin bedded grayish brown shale with some chert	0	6

Columbus limestone.

7.	Zone H. "Bone bed," well defined	..	..
6.	Bluish gray limestone in six to eight-inch beds and containing three horizons of fossiliferous white chert. All quite fossiliferous	9	4
5.	"Smooth layer," a similar layer occurring eight inches above, is often ripple or wave marked	..	..
4.	Zone G. Very fossiliferous gray limestone, rather thin bedded. The weathered surface shows numerous Corals	8	0
3.	Massive fossiliferous gray limestone. Shows prominent oblique joints running approximately north and south	12	0
2.	Zone F. Massive gray limestone exceedingly full of *Spirifer gregarius*	4	6
1.	Zone E. Massive bluish gray limestone containing an abundant fauna. Some petroleum occurs in the rock cavities (bottom of quarry)	2	6

The following fossils are more or less abundant here in the Columbus limestone.

	Zones.
Calcisphæra robusta Williamson	G
Aulacophyllum sulcatum (d'Orbigny)	G
Favosites emmonsi Rominger	E

	Zones.
Favosites hemisphericus (Troost)	F, G
Zaphrentis cornicula Edwards and Haime	G
Zaphrentis gigantea Rafinesque	E, G
Zaphrentis sp.	F
Stromatopora ponderosa Nicholson	G
Cystodictya gilberti (Meek)	G, H
Fenestella sp.	F
Atrypa reticularis (Linnæus)	E, F, G, H
Chonetes mucronatus Hall	G
Cyrtina hamiltonensis Hall	G
Delthyris raricosta Conrad	H
Leptæna rhomboidalis (Wilckens)	G, H
Nucleospira concinna Hall	H
Pentamerella arata (Conrad)	H
Rhipidomella vanuxemi Hall	F, G
Schizophoria propinque Hall	G
Spirifer acuminatus (Conrad)	H
Spirifer divaricatus Hall	G
Spirifer gregarius Clapp	E, F
Spirifer macrothyris Hall	E
Spirifer manni Hall	G
Stropheodonta demissa (Conrad)	E, G
Stropheodonta hemispherica Hall	E, G, H
Stropheodonta patersoni Hall	E, G
Stropheodonta perplana (Conrad)	E, F, G
Strophonella ampla Hall	E
Conocardium cuneus (Conrad)	E
Limopteria pauperata Hall	E, G
Modiomorpha concentrica (Conrad)	G
Mytilarca percarinata Whitfield	G
Paracyclas elliptica Hall	G
Bellerophon pelops Hall	G
Bellerophon sp.	G
Callonema bellatulum (Hall)	G
Euomphalus decewi Billings	G
Loxonema sp.	G
Macrocheilus sp.	G
Platyceras carinatum Hall	G
Platyceras dumosum Conrad	E, H
Platyceras sp.	G
Pleurotomaria lucina Hall	E, G
Pleurotomaria sp.	H
Turbo shumardi Verneuil	G (?)
Coleolus crenatocinctus Hall	F
Gomphoceras eximium Hall	G
Gomphoceras sp.	G
Gyroceras columbiense Whitfield	G
Gyroceras cyclops Hall	G
Gyroceras sp.	G
Orthoceras sp.	G
Phacops rana (Green)	F

5—S. G.—1,000.

Storage Dam.—A mile and a half north of Marble Cliff, the city of Columbus has constructed a large dam across the Scioto River in the creation of a reservoir for water supply. During the fall of 1905 the whole east bank was uncovered, exposing practically all of the more fossiliferous portion of the Columbus limestone. Prior to the beginning of work on this dam, the city engineering department drilled several test wells, which passed through the Devonian and into the Monroe formation of the Silurian. These wells were drilled with a diamond bit so that the drillings were secured in the form of solid cores, affording thus a means of observing the nature of the rock passed through, as well as the possibility of making an accurate measurement of its thickness.[1] There is thus a continuous section through the entire Columbus limestone, of which nearly two-thirds was actually exposed, while the remaining portion is given by a well record of exceptional value. This section therefore becomes a very important one among those of this formation in Ohio. Unfortunately, however, it is one destined to destruction because the filling of the reservoir has brought the water far up along the bank, and thus covered the greater part of the rock formerly exposed. The actual contact of the Columbus and Delaware limestones is not shown at the dam, but it may be found about a hundred yards to the south in a cut along the highway, and again in the Franklin Stone Company's quarry on the west bank just below the dam, where sixteen feet of the Delaware is exposed.

Columbus limestone.

		Ft.	In.
17.	Zone H. "Bone bed"	..	..
16.	Fairly massive bluish gray limestone	9	6
15.	"Smooth layer"	..	..
14.	Zone G. Even bedded bluish to gray limestone becoming quite massive	20	4
13.	Zone F. Massive bluish gray limestone containing large numbers of *Spirifer gregarius*. The cavities in the rock and the interior of many of the fossils are filled with petroleum	5	0
12.	Zone E. Massive bluish gray limestone containing numerous Corals and Brachiopods	16	0
11.	A layer made up largely of *Favosites emmonsi*	0	6
10.	Massive bluish gray limestone containing a large number of Corals, Brachiopods and some Gastropods	2	5
9.	Zone D. Massive grayish-brown limestone with some gray chert which contains some Brachiopods but few Gastropods	2	6

[1]Griggs, R. F., *Ohio Nat.*, Vol. IV, No. 3, 1904, pp. 67, 68.

		Ft.	In.
8.	Gray chert alternating with layers of light brown limestone. The lower layer of the chert contains a rich Gastropod fauna	6	4
7.	Light gray limestone containing little or no chert	0	6
6.	Zone C. Coral zone, made up largely of the genera *Favosites, Syringopora* and *Diphyphyllum.* The zone also contains Brachiopods and some chert	3	6
5.	Partly covered to the level of the Scioto River	2	8
4.	Zone B. (From the section of well No. 10.) Gravel and soil to top of rock	2	7
3.	Massive brown limestone	24	8
2.	Thinner bedded brown limestone	7	2
1.	Zone A. Conglomerate	2	4

Monroe Formation.

The following fauna was obtained here:

	Zones.
Calcisphæra robusta Williamson	G
Diphyphyllum archiaci Billings	H
Diphyphyllum simcoense (Billings)	C
Diphyphyllum verneuilanum (Edwards and Haime)	H
Favosites emmonsi Rominger	D
Favosites hemisphericus (Troost)	G
Heliophyllum halli Edwards and Haime	H
Syringopora tabulata Edwards and Haime	E
Zaphrentis cornicula Edwards and Haime	F, G
Zaphrentis gigantea Rafinesque	C
Zaphrentis prolifica Billings	G, H
Nucleocrinus verneuili (Troost)	H
Cystodictya gilberti (Meek)	G, H
Fenestella sp.	G
Monotrypa tenuis (Hall)	F
Atrypa reticularis (Linnæus)	C, D, E, F, G, H
Atrypa spinosa Hall	G, H
Camarotœchia sp.	F
Chonetes mucronatus Hall	C, G, H
Cyrtina hamiltonensis Hall	H
Delthyris raricosta Conrad	G
Leptæna rhomboidalis (Wilckens)	H
Meristella nasuta (Conrad)	E
Nucleospira concinna Hall	H
Reticularia fimbriata (Conrad)	H
Rhipidomella vanuxemi Hall	D
Schizophoria propinque Hall	G, H
Spirifer acuminatus (Conrad)	H
Spirifer duodenarius (Hall)	H
Spirifer gregarius Clapp	E, F

	Zones.
Spirifer macrothyris Hall	C, D, E
Spirifer manni Hall	D, E, H
Spirifer sp.	H
Stropheodonta demissa (Conrad)	G, H
Stropheodonta perplana (Conrad)	D, E, G, H
Stropheodonta hemispherica Hall	C, G, H
Strophonella ampla Hall	C, D
Aviculopecten sp.	H
Conocardium cuneus (Conrad)	D
Paracyclas elliptica Hall	C, G
Glossites teretis (?) Hall	H
Coleolus crenatocinctus Hall	D
Tentaculites scalariformis Hall	E, H
Bellerophon pelops Hall	D
Euomphalus decewi Billings	E
Loxonema pexatum Hall	D
Loxonema robustum Hall	D, G
Murchisonia maia Hall	D
Platyceras dumosum Conrad	H
Pleurotomaria lucina Hall	D, E, G
Phacops cristata Hall	D, G
Proetus crassimarginatus Hall	F

No. 11 of the above section is the layer which forms the bottom of the larger part of the Columbus Stone Company's quarry. It has been found to be quite persistent, occurring in many of the sections of Delaware county also. The evidence of this section and well record seems to substantiate the one hundred and thirty-eight feet referred to the Columbus and Delaware limestones in the State House well record.[1]

Dublin Pike.—From the Storage dam northward the banks of the Scioto formerly gave a section of the upper portion of the Columbus, which was practically continuous for several miles. Much of this is now covered, although many good sections still remain. The cuts along the Dublin turnpike, which follows the eastern side of the river, afford some excellent exposures of the Delaware limestone. These are of interest because they are among the best that occur south of the described sections, and also because they show some of the persistent characteristics of this formation. Near the north end of the new portion of the pike and a mile above Fishinger's bridge is perhaps the best section.

Delaware limestone.

		Ft.	In.
10.	Zone M. Brown limestone much weathered	0	9
9.	Zone L. Granular grayish limestone containing a large number of specimens of *Hadrophyllum d'orbignyi*	0	2

[1]*Geol. Surv. Ohio*, Vol, I, pt. 1, 1873, pp. 113, 114; also *Ibid.* Vol. VI, 1888, pp. 107, 108.

	Ft.	In.
8. Zone K. Thin blue limestone alternating with layers of black chert	5	7
7. Massive blue limestone	1	9
6. Nodules of chert and layers of cherty brown limestone	4	0
5. Zone J. Massive blue limestone with some chert	1	3
4. Thin bedded blue limestone	4	0
3 Zone I. Thin shaly limestone or shale, brown to bluish black in color. It has a strong odor of petroleum and contains the Marcellus fauna	8	10

Columbus limestone

2. Zone H. "Bone-bed"	..	..
1. Fossiliferous gray limestone	2	0

This section is the last to the south which gives enough of the Delaware limestone to expose the layer of *Hadrophyllum d'orbignyi.* From here this zone has been traced northward through every important section to Delaware, and, where the base of the formation is exposed, it has always been found about twenty-five feet above the "bone-bed." Because of its apparently constant horizon and persistent occurrence, it has been accorded a place in the general section, and furnishes a basis for the approximate determination of the location, in the formation, of outcrops which contain neither of the formational contacts.

The character of the lower layers of the Delaware limestone is well shown here. At the extreme north end of the cut it appears as a thin calcareous shale resting upon the Columbus limestone. Plate IX was taken in a small quarry about one hundred yards to the south of this section and between the highway and the reservoir. It gives an excellent idea of the sharpness of the contact between the Columbus and Delaware limestones, and the shaly character of the portion of rock immediately above the "bone-bed" as it is exhibited in Franklin county.

Fauna collected from the Delaware limestone in the above section:

	Zones.
Hadrophyllum d'orbignyi Edwards and Haime	L
Cystodictya gilberti (Meek)	K
Trematopora sp.	K
Ambocœlia umbonata (Conrad)	J
Chonetes scitulus Hall	J
Chonostrophia reversa Whitfield	I
Leiorhynchus limitare (Vanuxem)	I
Leptæna rhomboidalis (Wilckens)	J
Lingula ligea Hall	J
Martinia maia (Billings)	I
Orbiculoidea lodiensis (Vanuxem)	I

	Zones.
Orbiculoidea minuta (Hall)	I
Orthothetes chemungensis perversus (Hall)	J
Stropheodonta demissa (Conrad)	J
Stropheodonta inæquistriata (Conrad)	J
Stropheodonta perplana (Conrad)	J
Glyptodesma erectum (Conrad)	K
Tentaculites scalariformis Hall	J

Slate Run.[1]—Two and one-half miles north of the Storage dam, and on the east bank of the Scioto River, are the grounds of the Columbus Fishing Club. The pond is fed by a small stream known as Slate Run, which cuts through the Devonian shales and a part of the limestones. The base of the section, formerly exposed here, has been covered by the filling of the reservoir, but the more important part of the outcrop remains. The section as it was prior to the completion of the dam is as follows:

Ohio shale.

		Ft.	In.
24.	Thin bedded black shale obliquely jointed and containing large spherical concretions	12	6

Olentangy shale.

23.	Pale blue or bluish green soft argillaceous shale	2	0
22.	Rather indefinite layer of flat irregular limestone concretions	0	6
21.	Pale blue or bluish green gritless shale	14	0
20.	Blue limestone containing iron pyrites	0	5
19.	Soft bluish green shale	0	7
18.	Purplish brown shale with trail like markings of blue	0	2
17.	Bluish green shale with concretions of iron pyrites	0	4
16.	Purplish brown shale with markings of blue as above	0	2
15.	Bluish green marly shale with some thin brown layers	5	5

Delaware limestone.

14.	Zone M. Blue and gray to brown thin bedded limestone with layers of black chert	10	8
13.	Zone L. Not found in place. Blocks containing its fauna were found loose in the stream	0	3

[1]See Dr. Prosser's section, *Jour. Geol.*, Vol. XIII, 1905, pp. 426-430.

The shaly (Marcellus) phase of the Delaware limestone and its contact with the Columbus limestone in a small abandoned quarry along the east bank of the Scioto River, one mile north of Fishinger's Bridge, Franklin County.
(Photo by C. R. Stauffer.)

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		Ft.	In.
12.	Zone K. Uneven bedded brown limestone and layers of chert	4	4
11.	Zones J and K. Mostly thin even bedded brown limestone with layers of black chert	7	4
10.	Zone J. Thin bedded brown limestone and layers of black chert, both of which are somewhat folded	2	0
9.	Zone I. Brown shale with thin layers of black chert. This is the bank where Dr. Whitfield collected his "Marcellus" fauna	6	0

Columbus limestone.

8.	Zone H. "Bone bed"	..	..
7.	Rather massive crystalline gray limestone	8	0
6.	"Smooth layer"	..	..
5.	Zone G. Massive gray limestone, somewhat weathered	5	0
4.	Covered interval to level of fishing pond	5	4
3.	Partly covered from level of fishing pond to the top of the cliff below the highway	7	6
2.	Zone F and a part of Zone E. Very fossiliferous gray limestone. *Spirifer gregarius* being the must abundant in the upper part	12	0
1.	Covered to former level of the Scioto	5	6

Fauna from the Delaware limestone of this section:

	Zones.
Hadrophyllum d'orbignyi Edwards and Haime	L
Leiorhynchus limitare (Vanuxem)	I
Martinia maia (Billings)	I
Orbiculoidea lodiensis (Vanuxem)	I
Orbiculoidea minuta (Hall)	I
Rhipidomella sp.	K
Spirifer sp.	K
Aviculopecten princeps (Conrad)	M
Glyptodesma erectum (Conrad)	K
Nyassa arguta Hall	K

From the Columbus limestone:

	Zones.
Favosites hemisphericus (Troost)	G
Hadrophyllum d'orbignyi Edwards and Haime	H
Nucleocrinus verneuili (Troost)	H
Atrypa reticularis (Linnæus)	H
Chonetes mucronatus Hall	H
Eunella lincklæni Hall	H
Leptæna rhomboidalis (Wilckens)	H
Nucleospira concinna Hall	H

	Zones.
Pentamerella arata (Conrad)	H
Reticularia fimbriata (Conrad)	H
Rhipidomella vanuxemi Hall	H
Schizophoria propinque Hall	H
Spirifer acuminatus (Conrad)	H
Spirifer duodenarius (Hall)	H
Spirifer gregarius Clapp	F
Spirifer macrus Hall	H
Stropheodonta hemispherica Hall	H
Paracyclas elliptica Hall	G
Pterinea flabellum (Conrad)	G
Coleolus crenatocinctus Hall	F
Tentaculites scalariformis Hall	H
Callonema lichas (Hall)	H
Euomphalus decewi Billings	G
Platyceras dumosum Conrad	H
Pleurotomaria arata Hall	F
Pleurotomaria lucina Hall	G
Coronura diurus (Green)	G

The limestone, especially that of the Delaware, is thrown into numerous gentle folds, and has a general dip to the southeast, so that an accurate measurement of the formation is rather difficult. In obtaining the above section the bedding planes were followed as much as possible, and the measurement was made with tape and hand level.

Concerning the Brachiopod fauna occurring in the brown shaly zone, No. 9 of this section, Prosser remarks; "It is to be noted that the abundant species of this zone [*Leiorhynchus limitare* (Vanuxem), *Orbiculoidea lodiensis* (Vanuxem), and *Orbiculoidea minuta* (Hall)] occur in the Marcellus shale and later Devonian formations of New York, instead of the Onondaga limestone, and therefore support Whitfield's conclusion that it is the 'equivalent of the Marcellus shale of New York.' "[1]

Hayden Falls.—Hayden Run enters the Scioto River from the west seven miles due northwest of Columbus, and two and one-half miles south of Dublin, at or near the line between Washington and Norwich townships in Franklin county. Some distance from the river this stream enters a narrow rocky gorge, and just before reaching its outlet it tumbles over a ledge of rock, forming a cascade known as Hayden Falls. The following is a section of the rocks exposed along the run:

Delaware limestone.

	Ft.	In.
11. Zone J. Brown to bluish brown limestone alternating with black chert. Layers from three to six inches thick	8	8
10. Zone I. Brown shale alternating with layers of brownish black chert. The shale contains the Marcellus fauna	10	8

[1] *Jour. Geol.*, Vol. XIII, No. 5, 1905, pp. 429, 430.

Columbus limestone.

	Ft.	In.
9. Zone H. "Bone bed"	..	..
8. Rather thin even bedded gray limestone containing numerous Crinoid stems and some fossiliferous gray chert	10	8
7. "Smooth layer"	..	..
6. Zone G. Massive gray limestone weathering into small blocks of thin uneven beds	21	4
5. Zone F. Consisting of one or two layers of massive gray limestone forming the top of the ledge over which the water plunges. The *Sp. gregarius* zone	5	7
4. Zone E. Massive gray limestone weathering into rather thin even layers. The weathered surface is of a light buff color	17	0
3. Zone D. Layers of fossiliferous chert alternating with thin gray to brown limestone. The chert zone	8	3
2. Zone C. Massive brown limestone containing a large number of Corals; the usual fauna of the Coral zone	4	5
1. Covered to the former level of the Scioto River	8	0

Fauna collected at the above locality:

Delaware limestone.

	Zones.
Leiorhynchus limitare (Vanuxem)	I
Orbiculoidea lodiensis (Vanuxem)	I
Tentaculites scalariformis Hall	I

Columbus limestone.

	Zones.
Calcisphæra robusta Williamson	G
Aulacophyllum convergens Hall	G
Aulacophyllum sulcatum (d'Orbigny)	G
Diphyphyllum verneuilanum (Edwards and Haime)	H
Cystiphyllum vesiculosum Goldfuss	G
Diphyphyllum archiaci (Edwards and Haime)	G
Diphyphyllum sp.	G
Favosites hemisphericus (Troost)	G, H
Heliophyllum halli Edwards and Haime	H
Zaphrentis cornicula Edwards and Haime	G
Zaphrentis prolifica Billings	G, H
Zaphrentis wortheni Nicholson	G
Stromatopora ponderosa Nicholson	G
Codaster pyramidatus Shumard	H
Nucleocrinus verneuili (Troost)	H
Cystodictya gilberti (Meek)	G
Fenestella sp.	H
Atrypa reticularis (Linnæus)	E, F

	Zones.
Atrypa spinosa Hall	F
Athyris vittata indianaensis n. var	E, F
Chonetes mucronatus Hall	E
Cyrtina hamiltonensis Hall	H
Delthyris raricosta Conrad	G
Leptæna rhomboidalis (Wilckens)	H
Pholidostrophia iowaensis (Owen)	H
Productella spinulicosta Hall	H
Rhipidomella cleobis Hall	E
Rhipidomella vanuxemi Hall	G
Spirifer acuminatus (Conrad)	H
Spirifer duodenarius (Hall)	H
Spirifer gregarius Clapp	E, F
Spirifer macrothyris Hall	E
Spirifer macrus Hall	E
Spirifer manni Hall	E
Stropheodonta demissa (Conrad)	G, H
Stropheodonta hemispherica Hall	G, H
Stropheodonta perplana (Conrad)	G
Strophonella ampla Hall	E
Conocardium cuneus (Conrad)	D, G
Glossites teretis (?) Hall	H
Modiomorpha concentrica (Conrad)	D
Paracyclas elliptica Hall	E, G, D
Pterinea flabellum (Conrad)	G
Callonema lichas (Hall)	G
Euomphalus decewi Billings	G
Loxonema pexatum Hall	G
Platyceras dumosum Conrad	H
Pleurotomaria lucina Hall	G
Tentaculites scalariformis Hall	H
Coronura diurus (Green)	E
Phacops cristata Hall	E, G

Perhaps the thing of most importance at Hayden Falls is the appearance of a natural section in which the chert zone (D) occurs, but the resistant character of the *Sp. gregarius* zone is no less interesting. The layer of massive gray limestone with its prominent bedding plane at the base is quite characteristic of this zone throughout the sections along the Scioto River and marks the "fall line" in all of these runs from Dublin southward.

Dublin.—This village is located along the west bank of the Scioto River in Washington township, Franklin county. Many and excellent sections are exposed here, but those usually given are taken from the east bank of the river where there is an outcrop of thirty-three feet of the Columbus limestone with the Delaware limestone showing in the hill above. The section given below may be found along Indian Run, which enters the Scioto from the west at the northern edge of town

Some little distance west of the highway this creek divides, and a short distance farther along the south fork is a double cascade, the lower one falling over a ledge of rock which lies in the *Sp. gregarius* zone.

Delaware limestone.

		Ft.	In.
11.	Zone I. Thin bedded fossiliferous grayish brown limestone with but little true shale and not sharply separated from the limestone below	5	10

Columbus limstone.

10.	Zone H. "Bone-bed," poorly defined	..	..
9.	Fairly massive gray limestone containing fish teeth and plates scattered throughout the upper part. This and the zone above may be seen in the old quarry above the upper cascade	8	6
8.	"Smooth layer"	..	..
7.	Zone G. Massive gray limestone along the cascade to the level of the lower waterfall	20	8
6.	Zone F. Massive gray limestone forming the top layers at the waterfall	5	0
5.	Zone E. Rather massive gray limestone and very fossiliferous	20	0
4.	Zone D. Layers of fossiliferous gray chert alternating with grayish brown limestones. The best outcrop is on the north bank below the highway arch	8	4
3.	Zone C. Gray to brown limestone, some quite crystalline. Corals abundant	3	6
2.	Zone B. Massive brown limestone irregularly bedded and obliquely jointed	3	0
1.	Covered to level of the Scioto River	7	4

The following fauna was collected from this locality:

	Zones.
Diphyphyllum archiaci Billings	C, E
Diphyphyllum sp.	C
Favosites emmonsi Rominger	C
Favosites hemisphericus (Troost)	F, G, H
Favosites radiciformis Rominger	C
Zaphrentis cornicula Edwards and Haime	F, G
Zaphrentis gigantea Rafinesque	C, E, F
Zaphrentis prolifica Billings	H
Zaphrentis sp.	E
Stromatopora ponderosa Nicholson	C, E
Megistocrinus spinulosus Lyon	H

	Zones.
Cystodictya gilberti (Meek)	E. F
Fenestella sp.	H
Monotrypa tenuis (Hall)	E
Polypora robusta (Hall)	E
Atrypa reticularis (Linnæus)	D, E, F, H
Atrypa spinosa Hall	D, E, F, G, H
Camarotœchia billingsi Hall	E
Chonetes mucronatus Hall	F, G
Crania crenistriata (?) Hall	E
Delthyris consobrina (d'Orbigny)	I
Eunella lincklæni Hall	F, H
Leiorhynchus limitare (Vanuxem)	I
Leptæna rhomboidalis (Wilckens)	E, H
Meristella nasuta (Conrad)	D, E
Nucleospira concinna Hall	D
Orbiculoidea lodiensis (Vanuxem)	I
Orthothetes pandora (Billings)	F
Reticularia fimbriata (Conrad)	F, H
Rhipidomella livia (Billings)	E, H
Rhipidomella vanuxemi Hall	D, E, F
Schizophoria propinque Hall	F, H
Spirifer acuminatus (Conrad)	H
Spirifer divaricatus Hall	E
Spirifer duodenarius (Hall)	H
Spirifer gregarius Clapp	E, F,G
Spirifer macrothyris Hall	E
Spirifer macrus (?) Hall	C, H
Spirifer manni Hall	E, F
Stropheodonta concava Hall	H
Stropheodonta demissa (Conrad)	E, H
Stropheodonta hemispherica Hall	D, E, F, H
Stropheodonta patersoni Hall	H
Stropheodonta perplana (Conrad)	E, H
Stropheodonta sp.	F
Strophonella ampla Hall	E
Aviculopecten cf. pecteniformis (Conrad)	H
Conocardium cuneus (Conrad)	D, E, F, G
Limopteria pauperata Hall	E
Modiomorpha concentrica (Conrad)	D, E
Nucula niotica (?) Hall and Whitfield	D
Paracyclas elliptica Hall	E, F
Bellerophon hyalina Hall	D
Bellerophon newberryi Meek	D
Bellerophon pelops Hall	D, E, F
Callonema bellatulum (Hall)	D
Callonema lichas (Hall)	E
Cœlidium strebloceras (?) Clarke	D
Cyclonema crenulatum Meek	D
Euomphalus decewi Billings	F
Isonema depressum Meek and Worthern	D
Loxonema gracillium Whiteaves	D
Loxonema læviusculum Hall	D

	Zones.
Loxonema parvulum Whitfield	D
Loxonema pexatum Hall	D
Loxonema sp.	D
Macrocheilus sp.	D
Murchisonia desiderata Hall	D
Murchisonia leda Hall	D
Murchisonia maia Hall	D
Murchisonia quadricarinata n. sp	D
Naticopsis æquistriata Meek	D
Naticopsis comperta Hall	D
Naticopsis sp.	D
Platyceras blatchleyi Kindle	H
Platyceras carinatum Hall	E, F
Platyceras cymbium Hall	E
Platyceras dumosum Conrad	H
Platyceras sp.	D
Pleurotomaria adjutor Hall	D
Pleurotomaria dublinensis n. sp	D
Pleurotomaria hyphantes Meek	D
Pleurotomaria lucina Hall	E, F, G
Pleurotomaria regulata (?) Hall	D
Turbo shumardi Verneuil	E, F
Coleolus crenatocinctus Hall	D. E
Tentaculites scalariformis Hall	G, H, I
Gomphoceras eximium Hall	E
Gyroceras columbiense Whitfield	E
Orthoceras ohioensis Hall	D
Coronura diurus (Green)	E
Odontocephalus bifidus Hall	E, H
Phacops cristata Hall	F
Proetus crassimarginatus Hall	D, F, H
Proetus rowii (Green)	F

Corbin's Mill.—At Corbin's Mill, which is located on the east side of the river and less than a mile above Dublin, Orton gives a section which covers all of the Delaware and forty-three feet of the Columbus limestone.[1] His measurement makes the chert zone occur only thirty feet below the "bone-bed," whereas it usually averages from fifty to fifty-five below the top of the Columbus limestone. This is evidently an error, as recent measurements show the interval to be normal. The rocks are somewhat folded and the gully winds considerably, so that errors are easily made. The following section is believed to be essentially correct:

Delaware limestone.

	Ft.	In.
9. Zone K. Thin bedded brown limestone and some chert	13	0
8. Zone J. Much black chert alternating with layers of brown limestone	8	0

[1]*Geol. Surv. Ohio*, Vol. III, 1878, p. 604.

	Ft.	In.
7. Zone I. Brown shale containing a fauna of *Leiorhynchus limitare,* etc., as found at other localities where this horizon is exposed	5	0

Columbus limestone.

6. Zone H. The "bone-bed" is not clearly shown. The upper part is a thin bedded almost shaly brown limestone	9	0
5. Zone G. A rather massive gray limestone, much weathered	21	0
4. Zone F. Massive gray limestone containing an abundance of fossils, among which *Sp. gregarius* is the most common	4	8
3. Zone E. A very fossiliferous massive gray to brownish gray limestone	17	10
2. Zone D. Layers of fossiliferous gray chert alternating with grayish brown limestone to the base of the cliff	3	1
1. Partly covered to level of the Scioto River	10	9

Although the rocks here are very fossiliferous, no attempt to make a representative collection was made. The few that were picked up are such as were also found along Indian Run.

Franklin-Delaware County Line.—In giving a section of the formation outcropping near this place, Winchell locates it "where the Scioto crosses the southern boundary of the county (Delaware) * * * in descending a ravine from the east, on the land of Abram Butts."[1] This ravine is located about one hundred and fifty yards north of the county line, and the land is now owned by Mr. Arthur Stickel, of Columbus. The small stream flowing through this ravine is sometimes called "Monkey Run." The following is a section of the rocks found here:

	Ft.	In.
6. Soil and drift	5	0

Columbus limestone.

5. Zone F. Massive gray Crinoidal limestone containing many specimens of *Spirifer gregarius*	3	0
4. Zone E. Very fossiliferous gray limestone in massive beds which weather into thin uneven layers and small blocks. The vertical walls show numerous oblique joints and the weathered surface has a gray-brown color	18	10

[1]*Geol. Surv. Ohio,* Vol. II, pt. 1, 1874, p. 297

	Ft.	In.
3. Zone D. Fossiliferous gray chert in two to four-inch layers alternating with six to twelve-inch layers of crystalline brown limestone	8	6
2. Zone C. The Coral zone appears to be wanting here; at least it is lacking in Corals	..	..
1. Zone B. Massive brown limestone, the upper part of which contains much bituminous matter. Between some of the layers there is a distinctly bituminous shale parting. Uneven beds from two to fourteen inches. It contains pockets of calcite crystals and some unfossiliferous gray chert. Weathered surface buff	13	0

A small but interesting collection of fossils was made at this locality.

	Zones.
Zaphrentis gigantea Rafinesque	E
Zaphrentis sp.	E
Dictyonema leroyensis Gurley	B
Semicoscinium bi-imbricatum (Hall)	D
Unitrypa tegulata Hall	D
Atrypa reticularis (Linnæus)	D, E, F
Chonetes mucronatus Hall	E
Meristella nasuta (Conrad)	D
Rhipidomella sp.	E
Schizophoria propinque Hall	E
Spirifer gregarius Clapp	F
Spirifer manni Hall	D
Stropheodonta hemispherica Hall	E
Conocardium cuneus (Conrad)	E
Bellerophon pelops Hall	D
Isonema humile Meek	D
Murchisonia sp.	D
Platyceras dumosum (?) Conrad	E
Pleurotomaria lucina Hall	E
Coronura diurus (Green)	E
Phacops cristata Hall	F

Winchell thought that from "ten to fifteen feet" of the formation is lacking here, and that his "Delhi beds," which are equivalent to about thirty feet of that portion of the Columbus limestone lying immediately below the base of the Delaware, rest directly upon the chert zone.[1] It is to be noted, however, that the top of this outcrop contains an abundance of *Spirifer gregarius*, and hence lies in Zone F, which is usually located about thirty feet below the "bone-bed" or upper limit of the Columbus limestone. The layers lying immediately above and below

[1]*Idem*, pp. 296, 297.

this zone frequently present very similar lithological characteristics and likewise weather into small blocks, which fall as talus at the base of the cliffs. That there is no thinning out of a portion of the formation is evident from the section which follows.

Deer Run.—Directly opposite the "section near the south line of Delaware county, in the east bank of the Scioto" which is given above and a section of which Winchell gives, there is a deep gorge cut by Deer Run, which enters the river three and a quarter miles north of Dublin and about an eighth of a mile north of the county line. The section may be found on lands owned by John Dun in Concord township, Delaware county. The cliffs are vertical walls of limestone at places nearly forty feet in height. They are but little weathered, and show the even character of the bedding excellently. This is one of the best outcrops that can be found among the many that occur along the Scioto River.

Columbus limestone.

	Ft.	In.
7. Zone H. Gray limestone, much weathered	7	6
6. Zone G. Massive gray limestone in even beds from ten to fourteen inches in thickness	20	0
5. Zone F. Massive gray limestone containing numerous specimens of *Spirifer gregarius*	4	5
4. Zone E. Massive gray limestone in layers from one to two and a half feet in thickness. Where much weathered these heavy beds are broken up into thin uneven layers. Weathered color dark gray, yellowish gray or buff	18	0
3. Zone D. Layers of fossiliferous gray chert alternating with brownish limestone	7	8
2. Zone C. The Coral zone is wanting	..	..
1. Zone B. Massive brown limestone with numerous oblique joints and in the bed of the run broken into irregular jagged blocks. It contains much bituminous matter and some pockets of calcite crystals	8	4

The following fauna was collected along this run:

	Zones.
Favosites hemisphericus (Troost)	G
Zaphrentis cornicula Edwards and Haime	G
Zaphrentis gigantea Rafinesque	F
Zaphrentis sp.	F
Fenestella parallela (?) Hall	D
Polypora robusta (?) (Hall)	D
Prismopora triquetra Hall	D
Stictopora sp.	D
Atrypa reticularis (Linnæus)	D, E, F, G

	Zones.
Chonetes mucronatus Hall	E, F, G, H
Crania sp.	D
Eunella lincklæni Hall	E, F
Leptæna rhomboidalis (Wilckens)	E
Meristella nasuta (Conrad)	D
Nucleospira concinna Hall	E
Pholidostrophia iowaensis (Owen)	F
Rhipidomella vanuxemi Hall	E
Schizophoria propinque Hall	E, F
Spirifer acuminatus (Conrad)	H
Spirifer divaricatus Hall	E, F
Spirifer gregarius Clapp	E, F, G
Spirifer macrothyris Hall	E
Spirifer macrus Hall	D, E, F
Spirifer manni Hall	E
Stropheodonta hemispherica Hall	D, E, F, G
Stropheodonta perplana (Conrad)	F
Stropheodonta inæquistriata (Conrad)	D, E, F, G
Strophonella ampla Hall	E
Conocardium cuneus (Conrad)	D, E, F, G
Limopteria pauperata (?) Hall	G
Modiomorpha concentrica (Conrad)	E
Mytilarca percarinata Whitfield	D, E
Nucula niotica (?) Hall and Whitfield	D
Paracyclas elliptica Hall	E, G
Bellerophon newberryi Meek	D
Bellerophon pelops Hall	D, E
Callonema bellatulum (Hall)	D
Callonema lichas (Hall)	E, F
Dentalium martini Whitfield	D
Euomphalus decewi Billings	E, G
Isonema depressum Meek and Worthen	D
Loxonema pexatum Hall	D, G
Loxonema robustum Hall	D
Murchisonia desiderata Hall	D
Murchisonia desiderata var. Hall	D
Murchisonia maia Hall	D
Naticopsis æquistriata Meek	D
Orthonema newberryi Meek	D
Platyceras attenuatum Hall	E
Platyceras carinatum Hall	E
Platyceras dumosum Conrad	F
Pleurotomaria adjutor Hall	D
Pleurotomaria lucina Hall	D, E
Pleurotomaria sp.	D
Turbo shumardi Verneuil	D
Coleolus crenatocinctus Hall	F
Gyroceras cyclops Hall	G
Gyroceratites ohioensis Meek	E
Orthoceras ohioense Hall	D, E
Coronura diurus (Green)	G
Phacops cristata Hall	F, G

A comparison of this section with the preceding one shows them to be practically identical, except that this one has a much greater extension above the chert zone. This indicates that every member of the Columbus, except a small portion of the top which has been removed by erosion, is here represented in its usual thickness. The distance between these two sections is scarcely three hundred yards.

The absence of Corals in the zone where they generally occur is also to be noted. The limestone of this horizon is much darker in color and contains more of the thin bituminous layers at the top than usual. The contact between this lower portion and the overlying chert zone has many of the features of an unconformity, and it may be that this locality was temporarily above the sea, while surrounding areas were supporting a rich Coral fauna. At any rate, conditions here were unfavorable for Coral life, and the presence of a quantity of bituminous matter suggests the presence of plant life. This portion of the formation has a similar appearance at other localities, the most striking of which perhaps is that at Robinson's lime-kiln near Rathbone. Here there are no Corals at this horizon, and the indications of unconformity are so strong that it has been suggested as the dividing line between two formations. The break is, however, not always apparent, nor is the faunal evidence in favor of such a division. Possibly it may be used to advantage to indicate the dividing line between the upper and lower portions of the Columbus limestone—two portions of a single formation divided rather on lithological structure and scarcity of fossils in the lower part than on real faunal differences.

Eversole Run.—This run is located in Concord township, about two miles north of the south line of Delaware county, and enters the Scioto River from the west, flowing between the old Robinson or Courtwright and the Depp farms. It cuts an interesting gorge in the Columbus limestone, of which the following is a section:

Columbus limestone.

	Ft.	In.
4. Zone E. Massive gray limestone, very fossiliferous, and especially so near the base, where it contains a rather distinct layer of Corals	16	0
3. Zone D. Gray chert alternating with brown limestone. The best exposure of this zone is at the foot of Robinson hill. A detailed measurement of the chert zone at this locality is given later	5	10
2. Zone C. Massive brown limestone which near the highway is a mass of Corals	2	0
1. Zone B. Massive brown limestone, uneven bedded and showing numerous oblique joints. Fossils rare except in the cherty nodules that occasionally occur	19	4

A rather full collection of fossils from this section yielded the following fauna:

	Zones.
Cladopora pulchra Rominger	B, C
Cladopora robusta Rominger	C
Diphyphyllum simcoense (Billings)	B, C
Diphyphyllum strictum Edwards and Haime	C
Favosites emmonsi Rominger	C, D, E
Favosites hemisphericus (Troost)	D, E
Syringopora tabulata Edwards and Haime	C, D
Zaphrentis cornicula Edwards and Haime	D
Zaphrentis gigantea Rafinesque	B, C, E
Stromatopora ponderosa Nicholson	C, D, E
Coscinium striatum Hall and Simpson	D
Cystodictya gilberti (Meek)	D
Fenestella parallela Hall	D
Fenestella sp.	B
Fistulipora substellata (?) Hall	B
Lichenalia sp.	D
Monotrypa tenuis (Hall)	D
Nemataxis fibrosus Hall	B, D
Polypora celsipora (Hall)	D
Polypora flabelliformis (?) (Hall)	D
Polypora hexagonalis (Hall)	D
Polypora robusta (Hall)	D
Prismopora triquetra (Hall)	D
Stictopora sp.	D
Atrypa reticularis (Linnæus)	C, D, E
Atrypa spinosa (?) Hall	D, E
Camarotœchia billingsi Hall	B
Camarotœchia tethys (Billings)	C, D
Chonetes mucronatus Hall	D
Crania crenistriata (?) Hall	D
Cyrtina hamiltonensis Hall	D
Delthyris raricosta Conrad	E
Eunella lincklæni Hall	C, D
Leptæna rhomboidalis (Wilckens)	D
Meristella nasuta (Conrad)	B, D, E
Meristella rostrata (?) Hall	C
Nucleospira concinna Hall	D
Orthothetes pandora (Billings)	D
Pholidostrophia iowaensis (Owen)	D
Productella spinulicosta Hall	D, E
Reticularia fimbriata (Conrad)	C, D
Rhipidomella vanuxemi Hall	D, E
Schizophoria propinque Hall	D, E
Spirifer divaricatus Hall	D, E
Spirifer gregarius Clapp	E
Spirifer macrothyris Hall	D, E
Spirifer macrus Hall	B, C, D
Spirifer manni Hall	D, E
Spirifer varicosus Hall	D
Stropheodonta demissa (Conrad)	B, D

	Zones.
Stropheodonta hemispherica Hall	B, C, D, E
Stropheodonta inæquistriata (Conrad)	C, D, E
Stropheodonta patersoni Hall	E
Stropheodonta perplana (Conrad)	D
Strophonella ampla Hall	B, D, E
Actinopteria boydi (Conrad)	D
Actinopteria sp	C
Aviculopecten cleon Hall	C
Conocardium cuneus (Conrad)	B, D, E
Conocardium cuneus attenuatum (Conrad)	D
Conocardium cuneus trigonale Hall	D
Conocardium ohioense Meek	D
Glossites teretis Hall	D
Goniophora hamiltonensis (?) Hall	D
Grammysia secunda (?) Hall	D
Grammysia subarcuata (?) Hall	D
Modiomorpha concentrica (Conrad)	D, E
Mytilarca percarinata Whitfield	D
Nucula niotica Hall and Whitfield	D
Nucula sp.	D
Paracyclas ohioensis Meek	C, D
Plethomytilus ponderosa Hall	D
Schizodus contractus Hall	D
Schizodus tumidus Hall	D
Solemya vestuta Meek	D
Bellerophon hyalina Hall	D
Bellerophon newberryi Meek	D
Bellerophon pelops Hall	D, E
Bellerophon rotalinea (?) Hall	D
Bellerophon sp.	D
Callonema bellatulum (Hall)	D
Callonema clarki Nettelroth	D
Callonema imitator (Hall and Whitfield)	D
Callonema lichas (Hall)	D, E
Cyclonema crenulatum Meek	D
Dentalium martini Whitfield	D
Euomphalus decewi Billings	E
Isonema depressum Meek and Worthen	D
Isonema humile Meek	D
Loxonema gracillium Whiteaves	D
Loxonema læviusculum Hall	D
Loxonema parvulum Whitfield	D
Loxonema pexatum Hall	D
Loxonema pexatum obsoletum Hall	D
Loxonema robustum Hall	D
Loxonema sp.	D
Macrocheilus hebe Hall	D
Macrocheilus macrostoma Hall	D
Macrocheilus prisca Whitfield	D
Murchisonia desiderata Hall	D
Murchisonia desiderata var. Hall	D
Murchisonia eversolensis n. sp	D
Murchisonia intermedia n. sp	D

	Zones.
Murchisonia leda Hall	D
Murchisonia maia Hall	D
Murchisonia quadricarinata n. sp	D
Naticopsis æquistriata Meek	D
Naticopsis comperta Hall	D
Naticopsis lævis Meek	D
Platyceras bucculentum Hall	D
Platyceras carinatum Hall	D
Platyceras dumosum (?) Conrad	D
Platyceras thetis Hall	D
Platyceras sp.	D
Platystoma lineatum Conrad	D
Platystoma subglobosa n. sp.	D
Pleurotomaria adjutor Hall	D
Pleurotomaria cancellata n. sp	D
Pleurotomaria cf. capillaria Hall	D
Pleurotomaria dublinensis n. sp	D
Pleurotomaria hyphantes Meek	D
Pleurotomaria insolita Hall	D
Pleurotomaria lucina Hall	D, E
Pleurotomaria plena Hall	D
Pleurotomaria procteri Nettelroth	D
Pleurotomaria sciotoensis n. sp	D
Pleurotomaria sp.	D
Pseudophorus antiquus Meek	D
Straparollus corrugatus n. sp	D
Strophostylas varians Hall	D
Turbo shumardi Verneuil	E
Coleolus crenatocinctus Hall	D, E
Tentaculites scalariformis Hall	D
Agoniatites discoideus (Hall)	D
Cyrtoceras cretaceum Whitfield	E
Cyrtoceras metula (?) Hall	D
Cyrtoceratites ohioensis Meek	D
Gyroceras columbiense Whitfield	D
Orthoceras nuntium Hall	D
Orthoceras ohioense Hall	D
Orthoceras sirpus Hall	D
Orthoceras thoas Hall	D
Chasmops archiops Hall	D
Dalmanites sp.	D
Phacops cristata Hall	D, E

Chert is a rather common constituent of the Columbus limestone, as is also the case in its eastern equivalent, the Onondaga of New York. At Bellefontaine, Whitehouse, Marblehead, Marion, and Columbus rather extensive beds of this material occur, and yet an examination of these various sections shows that in all probability they occur at as many different horizons. They bear different relations to certain faunal groups and other more or less constant features of the formation, but, what is more important, these chert beds have very different faunas.

Zone D of the above section, and occurring also in many of the previously mentioned sections, lies from fifty to fifty-five feet below the "bone-bed" or top of the formation and immediately above a very prominent fossil Coral reef. The outcrop of this chert zone in Eversole Run is exceedingly fine. (See Plate X). It will be observed, however, that there has been a rapid decrease in its thickness, as compared with sections farther south. This thinning out continues northward until two miles above the Girls' Industrial Home at Rathbone, Delaware county, no trace of it can be found, but at Robinson's lime-kiln (now abandoned), one mile south of the Rathbone bridge and on the east bank of the Scioto River, the zone measures four feet. From thence southward it gradually increases in thickness until at the section exposed during the construction of the Columbus Storage Dam, it has attained the maximum measurement of nine and one-third feet. This zone also forms the floor of the western part of the Columbus Stone Company's quarry at Marble Cliff, but at that point it passes under cover and is lost to observation.

Outcrops of this chert are abundant along the Scioto River and its tributaries from Columbus northward as far as the zone extends. Perhaps the most noted of these is that on the east bank of the river at Dublin, from which locality many of the species figured and described by James Hall and R. P. Whitfield were collected. Orton discusses this zone[1] in connection with his Corbin's Mill section, and Winchell calls attention to it in his "section near the south line of Delaware county,"[2] but his No. 2 includes rather more than is here considered a part of this zone. Some distance below the beds under discussion, occur scattered masses of chert which from their mode of occurrence and scarcity of fossils, are easily distinguished from the upper and more definite zone. It is this lower and almost non-fossiliferous chert which occurs along Mill Creek at Bellepoint.[3]

The best outcrop of this chert zone, so far as a collecting ground is concerned and also as a typical exposure, although slightly diminished in thickness, is at the foot of Robinson hill on Eversole Run. (See Plate X.). Here the zone has a thickness of five and five-sixths feet, consisting of the usual cherty layers alternating with rather thin limestones as follows:

		Inches.
10.	Gray chert and grayish brown limestone intermingled	3
9.	Grayish brown limestone	3
8.	Gray chert and grayish brown limestone	3
7.	Grayish brown limestone	5
6.	Gray chert imbedded in grayish brown limestone but mostly chert which is very fossiliferous	12
5.	Grayish brown limestone	2

[1] *Geol. Surv. Ohio*, Vol. III, 1878, p. 605.
[2] *Idem*, Vol. II, pt. 1, 1874, p. 297. [3] *Idem*, p. 298.

The outcrop of the chert or Gastropod zone in the Columbus limestone at the foot of Robinson's Hill, along the north bank of Eversole Run, Delaware County.

(Photo by J. E. Hyde.)

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		Inches.
4.	Gray chert with some grayish brown limestone...	9
3.	Grayish brown limestone.....	12
2.	Gray chert imbedded in grayish brown limestone	7
1.	Hard crystalline grayish brown limestone with a few nodules of gray chert in the upper part...	14

The chert occurs mostly as concretionary masses imbedded in the limestone, but sometimes these become so numerous as to practically exclude the latter and form more or less continuous layers of chert alternating with limestone. Much of the chert is hard and flint-like, but some of it, especially where much weathered, is soft and even chalky in appearance.

By far the greater majority of the fossils were obtained from No. 6 of the above section, and likewise No. 1 is especially rich in fine specimens of *Meristella nasuta*, but since most of the specimens were also found to occur in the other portions of the section, the fauna is given together for the whole zone. The fauna is rather remarkable in that many of the species are somewhat under size, but they are all well preserved, and show the smallest external markings excellently, and in some cases even traces of the original color. It is unfortunate, however, that they are frequently much cracked and broken. Perhaps the most remarkable feature about the fauna is the number of Gastropods which it contains.

The chert occurring below the Coral zone of this vicinity, is also of a gray color and fossiliferous, but it differs from that of the true chert zone in its mode of occurrence and in its fauna. It is found scattered irregularly through the limestone, and its meager and poorly preserved fossils cannot be classified as a Gastropod fauna. As the true chert zone (D) disappears, this lower chert becomes more prominent, but never assumes the definite character of Zone D. This part of the formation may also be seen in an excellent cliff on the east bank of the Scioto just opposite the mouth of Eversole Run.

A short distance above the Cox and Thomas mill, and about one and one-half miles south of Bellpoint, thirty-one feet of the massive brown limestone forming the lower part of the Columbus limestone outcrops in a cliff on the west bank of the river. This is capped by three and three-quarters feet of brown limestone, which is but a mass of Corals. In the field near by these are weathering out and lie strewn over the ground much like one might expect to find the fragments along a present day reef. These specimens, however, are not well preserved, and much difficulty was experienced in attempting to identify the fragments picked up. Among the abundant forms, however, the following may be recognized:

Cladopora tela (?) Davis
Cyathophyllum multigematum (?) Davis
Diphyphyllum stramineum Edwards and Haime

Diphyphyllum strictum (?) (Edwards and Haime)
Favosites emmonsi Rominger
Favosites hemisphericus (Troost)
Zaphrentis gigantea Edwards and Haime

Bellepoint.—This village is located at the junction of Mill Creek and the Scioto River in Delaware county. Opposite the mouth of Mill Creek is an old quarry and a small run. These, combined with the bold cliff-like river bank give the following section.

	Ft.	In.
8. Soil and drift	2	0

Columbus limestone.

	Ft.	In.
7. Zone F. Thin layers of gray limestone much weathered. It carries the *Spirifer gregarius* fauna	1	0
6. Zone E. Very fossiliferous massive gray limestone	17	6
5. Zone D. Eversole chert wanting	..	..
4. Zone C. Brown limestone containing numerous Corals	5	4
3. Zone B. Massive brown limestone with little or no chert	6	0
2. Massive brown limestone with irregular pockets of fossiliferous gray chert	5	4
1. Massive brown limestone with oblique joints and showing little or no bedding to Scioto River level	10	8

The following is a list of the fossils obtained here:

Syringopora tabulata Edwards and Haime	B
Zaphrentis gigantea (?) Rafinesque	B, C
Fenestella erectipora (?) Hall	B
Fenestella sp.	B
Nemataxis fibrosus Hall	B
Atrypa reticularis (Linnæus)	E
Meristella sp.	B
Schizophoria propinque Hall	E
Spirifer divaricatus Hall	E
Spirifer gregarius Clapp	E, F
Spirifer macrothyris Hall	E
Stropheodonta hemispherica Hall	E
Strophonella ampla Hall	E
Conocardium cuneus (Conrad)	B, E
Modiomorphia concentrica (Conrad)	E
Plethomytilus ponderosa Hall	E
Bellerophon pelops Hall	E
Pleurotomaria lucina Hall	E
Pleurotomaria sp.	B
Coleolus crenatocinctus Hall	E

Orthoceras ohioense Hall	E
Orthoceras thoas Hall	E
Coronura diurus (Green)	E
Phacops cristata Hall	E

The complete absence of the chert zone at this locality is perhaps the most important feature of the section. It is true that this particular portion is not well exposed where the section was measured, but just north of the bridge over the Scioto, and on the same side of the river, is an old quarry in which the base is formed by the Coral zone. The limestone above it contains no chert, although it does appear to have at least a part of the chert zone fauna.

Winchell says that "the water in Mill creek, at Bellpoint, is on No. 3 of the * * * section taken near the county line,[1] and has excavated a channel in it to the depth of fifteen feet, * * * Above these layers is a thickness of twelve feet of cherty beds."[2] These "cherty beds" are represented by numbers 2 and 3 of the section given above and are not Zone D of the General Section. This is easily determined by the mode of occurrence of the chert, its relation to the Coral zone, well shown here, and by the character of the rock within which it is imbedded, as well as its meager fauna. The amount of chert is relatively small and most of it is quite soft and chalk-like. It is found in pockets scattered more or less irregularly through the massive brown limestone below the Coral zone. Its fauna is small compared with that of the Eversole chert zone, and the specimens are frequently too poorly preserved to be definitely identified. Probably the best exposure of this chert is at the western edge of the village on the north side of the Mill Creek road. Here during the last few months of 1905 a small quarry was opened and the stone crushed for road material. The pit is entirely in the lower portion of the Columbus limestone, and there is exposed thirteen feet of dark brown limestone, with irregular pockets of soft white chert, capped by one and a half feet of brown limestone, which is best described as a mass of Corals.

Near the bridge across Mill Creek, one mile west of Bellepoint, is a prominent bluff on Mr. Cole's farm. Here the base of the Columbus limestone is shown near the level of the stream. The combined section of this bank and the small quarry and run in the immediate vicinity to the south, gives the following:

Columbus limestone.

	Ft.	In.
6. Zone E. Rather massive gray limestone weathering into thinner beds and quite fossiliferous	5	3
5. Zone D. Wanting	..	..

[1]See p. 62 of this report. [2]*Geol. Surv. Ohio*, Vol. II, pt. 1, 1874, p. 298.

	Ft.	In.
4. Zone C. Massive brown limestone containing numerous Corals, among which the abundant forms are *Favosites hemisphericus, Zaphrentis gigantea, Diphyphyllum simcoense, Favosites goldfussi,* etc. An excellent outcrop of the fossil reef.....	5	5
3. Zone B. Massive brown limestone containing some Corals,*Favosites maximus,* etc	30	4
2. Zone A. Conglomerate composed of water-worn pebbles of Monroe limestone imbedded in a matrix of brown Columbus limestone	1	6

Monroe limestone.

1. Fine grained drab dolomitic limestone showing a laminated structure. This rock continues to the bottom of Mill Creek channel	2	0

In discussing his section measured at this place, and which will be found to differ materially from the one given above, Winchell calls attention to the relatively constant horizon of the Coral zone, and to its occasional non-fossiliferous character; but he goes on to say that "No. 2 of this section embraces Nos. 2 and 3 of the section at the south county line in the east bank of the Scioto. The thin cherty layers are not so well defined as usual, and the thickness of both is somewhat reduced."[1] If this were true it would mean that the Eversole chert zone normally occurs below the Coral zone. It is a fact that there is frequently a thin layer of Corals lying immediately above this chert, but it has never been found to exceed about eight inches in thickness and often disappears within a few feet. Numerous sections, however, throughout Franklin and Delaware counties prove that the order given in the General Section is correct, and that the chert at the Franklin-Delaware county line, if it has a representative at Bellepoint and vicinity, is equivalent to the few layers of massive limestone overlying the Coral zone. The key to the problem is found in Eversole Run, where all of these zones occur in their true relation to each other.

Klondike Quarry.—This is located near White Sulphur station on the Big Four Railroad five and one-half miles west of Delaware, and two miles above Bellepoint. Wild Cat Run, which enters the Scioto River from the east, passes through the quarry. The section given below is of all the rocks exposed along the run:

Delaware limestone.

	Ft.	In.
11. Scattered outcrops of blue limestone and including the small quarry at the top. In all probability including Zones I, J and K in part.....	20	0

[1]*Idem*, pp. 299, 300.

Columbus limestone.

		Ft.	In.
10.	Zone H. "Bone-bed"	..	..
9.	Rather massive bluish gray limestone	10	0
8.	Zone G. Massive gray limestone, very fossiliferous	16	7
7.	Zone F. Massive gray limestone containing abundant *Spirifer gregarius*	3	5
6.	Zone E. Massive gray limestone forming the base of the quarry	9	10
5.	Massive gray limestone shown on the right bank of the run	4	0
4.	Zone D. Wanting	..	..
3.	Zone C. Brown limestone containing numerous Corals	4	8
2.	Zone B. Brown limestone weathering gray. It consists of irregular beds from six inches to one foot in thickness, shows a somewhat pitted structure, and contains some calcite crystals	13	4
1.	Covered to Scioto River level	2	3

This section, combined with the preceding one on Mill Creek, gives practically the entire Columbus limestone, although it does not measure up to the average for Franklin and Delaware counties. The absence of the chert zone is again noticeable.

Only a few species were collected at this locality.

	Zones.
Diphyphyllum simcoense Billings	C
Favosites goldfussi d'Orbigny	C
Stromatopora ponderosa Nicholson	C
Nucleocrinus verneuili (Troost)	H
Chonetes mucronatus Hall	F, K
Delthyris consobrina (d'Orbigny)	K
Nucleospira concinna Hall	F
Schizophoria propinque Hall	F
Spirifer gregarius Clapp	F
Spirifer macrothyris Hall	E
Conocardium cuneus (Conrad)	G
Modiomorpha cencentrica (Conrad)	F
Callonema lichas (Hall)	F
Coronura diurus (Green)	E

The Klondike quarry occupies the place where the Colvin lime-kilns were formerly located.[1] Since that time the rock has been extensively removed, the lower part being burned for lime, while the Delaware is crushed and shipped for road material.

The dip of the rock strata southward is greater than the gradient of the Scioto River, hence to the north the stream is flowing on older and

[1]See Prof. Winchell's section, *Geol. Surv. Ohio*, Vol. II, pt. 1, 1874, p. 295.

older strata. There are still some Devonian outcrops along the river to the north of Klondike quarry and on the hills of the east bank the Columbus limestone has been quarried and burned for lime, but scarcely a mile above White Sulphur station the river is flowing on the drab limestones of the Monroe formation. A half mile below Warrensburg the conglomerate of the base of the Columbus is excellently shown along the road on the east bank nearly twenty feet above the river. A mile north of Warrensburg the Scioto valley is broad and relatively flat; the east wall of the pre-glacial Scioto valley, across which the river has been forced, here retreats rapidly to the eastward, and no more important sections occur near the river channel.

The Olentangy River is the most important tributary to the Scioto. Northward from Columbus it too has a narrow valley with banks often cliff-like. Much of its outcrop is confined to the Devonian shales, but there are some very important sections which expose a large part of both limestones.

High Banks.—The Olentangy shale, the upper formation of the Middle Devonian, forms the lower part of the cliffs along the east bank of the Olentangy river at the boundary line between Franklin and Delaware counties. Here the following section is exposed:

	Ft.	In.
9. Drift	5	0
Ohio shale.		
8. Black shales with some concretions and several gray layers. This is limited below by a layer of large spherical concretions.	64	0
7. Fissile black shale	21	4
6. Black shales with some spherical concretions	10	8
Olentangy shale.		
5. Soft gray to bluish shales	4	4
4. Layer of flat bluish limestone concretions	0	4
3. Bluish gray shales with some layers of black shale	6	4
2. Layer of flat bluish gray limestone concretions	0	4
1. Bluish gray and brown shales to level of Olentangy River	5	6

The Olentangy shale is exceedingly poor in fossils in central Ohio, and here not a trace of animal remains was found.

Bartholomew Run[1]—This little stream is located a mile north of

[1]*Idem*, pp. 288, 289.

the Franklin-Delaware county line, and enters the Olentangy River from the west, heading near Powell. Following is the section of rocks exposed here:

		Ft.	In.
26.	Soil and drift	15	0
	Ohio shale.		
25.	Black shale with large spherical concretions in abundance	16	0
	Olentangy shale.		
24.	Soft bluish shales, the upper part weathered or leached to a yellowish color	3	10
23.	Layer of flat, more or less circular concretions of blue limestone	0	7
22.	Soft blue shales with some brown layers	7	2
21.	Layer of bluish argillaceous limestone	0	6
20.	Bluish shale with some thin bands of brown or black	2	0
19.	Black shale resembling the Ohio shale. It contains many fragments of fossil plants	0	7
18.	Soft blue shale	1	0
17.	Black shale, cut into blocks by joints, and containing some iron pyrites	0	6
16.	Soft blue shale	1	8
15.	Two layers of blue limestone	0	4
14.	Bluish green shales with thin bands of brown shale	2	4
13.	Purplish brown shales with some "worm" trails in blue and fragments of fossil plants	0	3
12.	Soft bluish green shales containing great numbers of small limestone concretions	5	0
11.	Purplish brown shale with some "worm" trails in blue through it and containing a few Bryozoans	0	3
10.	Bluish green shales, soft and gritless, showing some "worm" trails	2	4
	Delaware limestone.		
9.	Zone M. Cherty bluish brown limestone with "worm" trails penetrating it and filled with the blue shales of the overlying formation. In the uppermost part fish teeth and spines, more or less water worn, are common. Some pebbles were also found and iron pyrites is common	0	5
8.	Very cherty bluish brown limestone. Layers rather even and sparingly fossiliferous	9	8

		Ft.	In.
7.	Zone L. Layer of granular limestone containing numerous specimens of *Hadrophyllum d'orbignyi.* This zone contains much iron pyrites which has weathered to oxide at the surface. Many of the fossils have been replaced by iron.....	0	8
6.	Zone K. Massive blue limestone containing very little chert.....	2	0
5.	Thin bedded layers of shaly brown limestone containing much black chert..	1	0
4.	Blue limestone containing iron pyrites and black chert intermingled and much contorted	4	0
.3	Zone J. Rather massive blue limestone with some black chert and some shaly layers	8	0
2.	Zone I. Thin brown calcareous shale with layers of black chert.....	7	0
1.	Brown limestone, somewhat shaly and probably a part of the Delaware, to level of the run below the highway bridge	2	6

This is one of the few places where the contact between the Olentangy shale and the Delaware limestone may be observed, and it is quite probable that this will not remain free from the debris which is continually sliding down the shale cliff.

The fauna collected contains many of the most characteristic species of the Delaware limestone.

	Zones.
Hadrophyllum d'orbignyi Edwards and Haime.....	L
Cystodictya gilberti (Meek).....	K, L
Trematella arborea (?) (Hall).....	L
Camarotœchia tethys (Billings).....	L
Chonetes mucronatus Hall.....	J, L, M
Chonostrophia reversa (Whitfield).....	J, L
Eunella lincklæni Hall.....	L
Leiorhynchus limitare (Vanuxem.....	I, J
Leptæna rhomboidalis (Wilckens).....	J
Lingula ligea Hall.....	J
Orbiculoidea lodiensis (Vanuxem).....	I
Orbiculoidea minuta (Hall)	I
Pholidostrophia iowaensis (Owen).....	L
Rhipidomella vanuexmi Hall.....	K
Spirifer audaculus macronotus Hall.....	L
Spirifer macrus Hall.....	L
Stropheodonta demissa (Conrad).....	K, L
Stropheodonta hemispherica Hall	L, M
Stropheodonta perplana (Conrad).....	L
Glyptodesma erectum (Conrad)	J
Platyceras erectum (Hall)	J
Tentaculites scalariformis Hall	I, J

The layer containing *Ligula ligea* lies a little above the center of Zone J, and contains this species in great abundance, and associated with it is *Glyptodesma erectum*. It will be noted that both of these are strictly Hamilton species.

Aside from the plant remains and few worm-like trails, little in the way of fossils was collected from the Olentangy shale at this locality. A fragmentary Pelecypod of undetermined genus, but probably a *Nucula*, a single Crinoid segment, and a probably Bryozoan, constitute the entire collection.

Deep Run.—This run enters the Olentangy River from the east, about a mile and a half north of the preceding section, or two and one-half miles north of the south line of Delaware county. Its gorge gives a fine section of the Devonian shales and part of the limestones, showing a full development of the Delaware.[1]

Ohio shale.

		Ft.	In.
17.	Black shale showing its characteristic nearly right angled system of joints	56	0
16.	Rather fissile black shale weathering brown and containing some large spherical concretions	21	4

Olentangy shale.

15.	Soft bluish gray argillaceous shales. The contact with the overlying Ohio shale well shown	4	0
14.	Irregular flat bluish limestone concretions	0	4
13	Bluish gray shale with some thin layers of brown shale	5	8
12.	A rather definite layer of flat blue limestone concretions	0	2
11.	Soft bluish shale	1	0
10.	Bluish argillaceous limestone	0	4
9.	Soft blue shale	12	0

Delaware limestone.

8.	Zone M. More or less covered at contact with the above shale. A brown limestone	10	0
7.	Zone L. Layer of granular limestone containing *Hadrophyllum d'orbignyi*	0	3
6.	Zone K. Cherty brown limestone	4	4
5.	Bluish brown limestone alternating with black chert and much of it contorted	5	0

[1]See Dr. Prosser's section, *Jour. Geol.*, Vol. XIII, No. 5, 1905, pp. 430, 431; also Prof. Winchell's section, *Geol. Surv. Ohio*, Vol. II, pt. 1, 1874, pp. 293, 294.

		Ft.	In.
4.	Zone J. Somewhat massive bluish limestone alternating with black chert. *Tentaculites scalariformis* is a very common fossil..	4	10
3.	Zone I. (?) Brown shale alternating with black chert. Somewhat folded.....	7	0
2.	Rather massive layers of brown limestone showing a tendency to split into thinner layers. This rock resembles the deposit at the same horizon along Bartholomew Run and there referred to the Delaware, to which it probably belongs	6	7

Columbus limestone.

1.	No distinct "bone-bed" could be found. Much weathered very fossiliferous blue and gray limestone to level of Olentangy River	21	8

The fauna of this section was not collected.

Case Run.—On the same side of the river, and about one and one-half miles further north, is the farm now controlled by Amelia Case[1]. A small run passing by the house cuts a section which gives practically all of the Delaware limestone, while farther up stream is an interesting cliff, known as "Dripping Rock," where the Olentangy and Ohio shales are exposed. The loose material of this run furnishes one of the finest collecting grounds known for the Delaware limestone.

		Ft.	In.
16.	Black shale with some large spherical concretions	27	8

Olentangy shale.

15.	Bluish gray soft argillaceous shale.....	3	8
14.	Layer of blue limestone concretions.....	0	3
13.	Soft bluish shale.....	3	6
12.	Occasional flattened limestone concretions..	0	4
11.	Soft bluish shale.....	2	0
10.	Layer of bluish limestone.....	0	4
9.	Soft bluish shale mostly covered.....	21	0

Delaware limestone.

8.	Zone M. Massive hard blue limestone with but little chert.....	8	6
7.	Zone L. Granular layer containing *Hadrophyllum d'orbignyi.* This zone is exposed just below the barn.....	0	3

[1]See Prosser in *Jour. Geol.*, Vol. XIII, 1905, p. 432, on which is the halftone shown in Plate xi.

This illustration shows the thin bedded and cherty character of a large part of the Delaware limestone along Case Run, Delaware County.

(Photo by C. S. Prosser.)

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		Ft.	In.
6.	Zone K. Layers of blue limestone, six inches in thickness, and thin shaly layers with much grayish brown chert	7	6
5.	Thin bedded blue limestone with some chert	3	6
4.	Zone J. Massive bluish brown limestone with no chert	2	0
3.	Thin shaly brown limestone alternating with layers of black chert	5	10
2.	Thin bedded brown limestone with some irregular nodules of chert	2	0
1.	Zone I. Thin bedded blue limestone to bottom of run at highway bridge	3	8

Most of the following collection was made from the loose material near the highway bridge, hence no horizon can be assigned to it, although it is certainly all from the Delaware limestone.

Aulopora serpens Goldfuss
Zaphrentis sp.
Hadrophyllum d'orbignyi Edwards and Haime
Cystodictya gilberti (Meek)
Monotrypa tenuis (Hall)
Ambocœlia umbonata (Conrad)
Camarotœchia prolifica Hall
Chonetes mucronatus Hall
Chonetes scitulus Hall
Cyrtinia hamiltonensis Hall
Delthyris consobrina (d'Orbigny)
Eunella linckæni Hall
Leiorhynchus limitare (Vanuxem)
Leptæna rhomboidalis (Wilckens)
Lingula manni Hall.
Martinia maia (Billings)
Orbiculoidea doria (?) (Hall)
Orbiculoidea lodiensis (Vanuxem)
Orbiculoidea sp.
Orthothetes pandora (Billings)
Pholidostrophia iowaensis (Owen)
Productella spinulicosta Hall
Reticularia fimbriata (Conrad)
Rhipidomella vanuxemi Hall
Rhipidomella sp.
Spirifer macrus Hall
Spirifer sp.
Stropheodonta concava (?) Hall
Stropheodonta demissa (Conrad)
Stropheodonta perplana (Conrad)
Aviculopecten cleon Hall
Aviculopecten princeps (Conrad)
Glyptodesma erectum (Conrad)
Nyassa arguta (?) Hall

Paracyclas lirata (Conrad)
Platyceras dumosum Conrad
Platyceras erectum (Hall)
Platyceras sp.
Proetus sp.

A striking feature of this outcrop is the shaly character of a large part of the Delaware limestone. (See Plate XI). This same condition may be observed at many of the outcrops along the Olentangy River. Also there is a tendency for the lower layers of the formation to become more massive, although they still carry the Marcellus fauna.

Harter Run.—This run is located just across the river and a half-mile south of the one previously discussed. It is a mile south of Liberty Church and scarcely two miles above the Powell road. There are some very good outcrops along this stream, but the section possesses interest, particularly because of the large amount of Columbus limestone here exposed. It is near the crest of one of the larger of the small east and west anticlines which affect the rocks of the southern part of Delaware county.

Delaware limestone.

	Ft.	In.
6. Thin bedded brown limestone alternating with layers of black chert. Scattered outcrops belonging to the two lower zones of this formation	15	0

Columbus limestone.

5. Zone H. Actual contact covered but some of the loose blocks show an excellent "bone-bed"	..	..
4. Bluish gray Crinoidal limestone in even layers	10	0
3. Zone G. Scattered outcrops of massive gray limestone	19	8
2. Zone F. Rather massive gray limestone containing *Spirifer gregarius*	3	4
1. Zone E. Massive gray limestone partly covered and much weathered in the cliff near the road at Mr. Harter's residence. Bottom of section at the base of the rocks at the highway arch	18	0

The following species were obtained along this run.

	Zones.
Cyathophyllum rugosum Hall	H
Nucleocrinus verneuili (Troost)	H
Atrypa reticularis (Linnæus)	F, G
Camarotœchia tethys (Billings)	H
Chonetes mucronatus Hall	G, H

	Zones.
Delthyris raricosta Conrad	G
Eunella lincklæni Hall	H
Leptæna rhomboidalis (Wilckens)	H
Martinia maia (Billings)	I
Schizophoria propinque Hall	H
Spirifer acuminatus (Conrad)	H
Spirifer macrus Hall	H
Spirifer gregarius Clapp	F, G
Stropheodonta hemispherica Hall	G, H
Stropheodonta perplana (Conrad)	H
Aviculopecten cleon Hall	H
Conocardium cuneus (Conrad)	G
Limopteria pauperata Hall	G
Paracyclas elliptica Hall	G
Euomphalus decewi Billings	G
Loxonema pexatum Hall	G
Pleurotomaria lucina Hall	G
Turbo shumardi Verneuil	G
Tentaculites scalariformis Hall	H
Gyroceras columbiense Whitfield	G
Gyroceras cyclops Hall	G
Chasmops calypso Hall	H
Phacops cristata (?) Hall	H

A few years ago this run found a subterranean outlet, so that the lower part of its course is now dry most of the time. Underground drainage is quite common in areas where the Devonian limestones form the bed rock. The caves, sinks and big springs along the Scioto Rver north of Dublin are excellent examples of this phenomenon. Some of these, as for example, those on the John Dun farm just south of Deer Run, are large enough to admi the body of a man, and one may crawl for many yards without meeting any serious difficulty. A similar, though lees extensive, set of sinks occur in the vicinity of Bellevue in the northern part of the state. The courses of these underground streams are controlled by the directions of the master joints, and it seems quite probable that these same factors have had a considerable influence even on the surface drainage.

Lewis Center.—The run which flows westward to the Olentangy River from this stop on the Columbus, Delaware and Marion Electric Railroad, cuts a fine section in the Devonian shales, and the larger part of the Delaware limestone, as follows:

Ohio shale.

	Ft.	In.
23. Black shale with some spherical concretions and some iron pyrites concretions. Also contains some fossil plants	35	0
22. Soft gray shales with some black layers in the upper part	10	0
21. Black shales with spherical concretions	25	0

Olentangy shale.

		Ft.	In.
20.	Soft blue shale	3	4
19.	Layer of flat blue limestone concretions	0	7
18.	Soft greenish blue shale	3	2
17.	Layer of irregular flat limestone concretions and much iron pyrites	0	3
16.	Soft bluish green shales	3	0
15.	Layer of blue limestone	0	5
14.	Soft bluish green shales with some layers of brown to black shale	16	0
13.	Layer of flat irregular limestone concretions	0	7
12.	Soft bluish green shales	1	6
11.	Layer of irregular flat limestone concretions	0	4
10.	Soft bluish green shales	2	0
9.	Layer of argillaceous blue limestone	0	6
8.	Soft bluish green shales, partly covered	8	0

Delaware limestone.

7.	Zone M. Bluish brown, rather massive limestone	9	6
6.	Zone L. Granular limestone containing *Hadrophyllum d'orbignyi*	0	3
5.	Zone K. Fossiliferous bluish brown limestone	0	10
4.	Granular Crinoidal limestone with some fossiliferous gray chert. Corals plentiful	1	3
3.	Layers of brown limestone and black chert much intermixed and contorted	3	0
2.	Bluish limestone alternating with black chert	4	0
1.	Zone J. Massive blue limestone quite fossiliferous to the level of Olentangy River	5	4

The fauna collected from this region is as follows:

	Zones.
Favosites emmonsi (?) Rominger	K
Hadrophyllum d'orbignyi Edwards and Haime	L
Heliophyllum halli Edwards and Haime	K
Zaphrentis sp.	K
Cystodictya gilberti (Meek)	L, M
Fistulipora vesiculata Hall and Simpson	L
Fistulipora sp.	L
Atrypa reticularis (Linnæus)	L, M
Camarotœchia billingsi (?) Hall	K
Camarotœchia tethys (Billings)	K
Camarotœchia sp.	K
Chonetes mucronatus Hall	K, M
Cyrtina hamiltonensis Hall	K
Delthyris consobrina (d'Orbigny)	L
Leptæna rhomboidalis (Wilckens)	K
Pholidostrophia iowaensis (Owen)	L, M

	Zones.
Productella spinulicosta Hall	K
Rhipidomella vanuxemi Hall	K, M
Spirifer audaculus macronotus Hall	K, L
Spirifer sp.	K, M
Stropheodonta concava Hall	L
Stropheodonta demissa (Conrad)	K, L, M
Stropheodonta perplana (Conrad)	K, M
Aviculopecten princeps (Conrad)	K, M
Conocardium sp.	L
Glyptodesma erectum (Conrad)	K
Grammysia bisulcata (Conrad)	K
Grammysia ovata Hall	K

At Liberty Church, which is just across the river and a little south, there is rather more of the Delaware shown. In the run at that point the shaly lower layers of the formation are exposed, and below these are again found the heavy beds which seem to intervene between it and the underlying formation.

North of this locality there are numerous outcrops of Middle Devonian, but they are hardly as good as that just given and practically duplicates of it in the kind of rock outcropping. One of the better of these sections may be found along Welsh Run, which is on the east side of the Olentangy River and about half way between Lewis Center and Stratford. Here there is an outcrop of thirty-five feet of the Delaware limestone, which is succeeded by a partly covered section of Olentangy shale, and then by an excellent outcrop of the Ohio shale.

Stratford.—The village of Stratford is located three miles south of Delaware. Here the Olentangy River is flowing on strata belonging to the Delaware formation. Several quarries have been opened in this vicinity, but none are being worked at the present time (1909). The limestone is in general more massive and contains less chert than it does farther south, and hence has furnished some excellent building stone for local use. The limestone shows a number of small folds.

The following section is exposed in the quarry by the school house north of the village and in the river at that point.

Delaware limestone.

		Ft.	In.
15.	Crinoidal blue limestone	1	2
14.	Layer of white chert	0	3
13.	Granular masses, of inconstant occurrence along the south side of the quarry, carrying an abundance of *Hadrophyllum d'orbignyi.* This layer is also well filled with fish teeth and spines. Doubtless the Zone L of the General Section	0	6
12.	Cherty layers alternating with blue limestone	4	3
11.	Rather massive hard blue limestone weathering into thin layers	1	9

		Ft.	In.
10.	Brown shaly limestone, quite fossiliferous..	1	2
9.	Thin bedded blue limestone.....	0	9
8.	Shale parting	0	2
7.	Blue limestone with much bluish white chert and shaly partings	1	6
6.	Rather massive bluish brown limestone with some chert	2	6
5.	Blue limestone with a conspicuous concoidal fracture, some bluish white chert and shaly partings	1	6
4.	Impure blue to brown shaly limestone.....	0	8
3.	A rather massive rough blue limestone, marked with various trails and especially *"Spirophyton cauda-galli"*	0	10
2.	Impure shaly blue to brown limestone.....	0	10
1.	Thin bedded weathered bluish limestone exposed in the river bed.....	1	6

It is quite probable that this section extends down nearly to the Columbus limestone, as a few blocks from the deeper part of the river appear to belong to that formation. The lower part of the section does not show the same shaly character that is observed in the Franklin county sections, but the fauna is suggestive of the same horizon. Even No. 10 of the section carries a *Leiorhynchus*, which is probably *L. limitare*.

The following is the fauna of this locality:

	Horizon.
Hadrophyllum d'orbignyi Edwards and Haime.....	13
Chonetes deflectus Hall.....	6, 10
Chonetes sp.	1
Chonostrophia reversa (Whitfield).....	1, 3
Cyrtina hamiltonensis Hall.....	3
Delthyris consobrina (d'Orbigny).....	1, 2, 4, 5, 6, 10
Leiorhynchus limitare (?) (Vanuxem).....	1, 3, 10
Leptæna rhomboidalis (Wilckens).....	12, 15
Lingula manni Hall.....	10
Lingula sp.	10
Martinia maia (Billings).....	3, 4, 10
Orbiculoidea lodiensis (Vanuxem).....	10
Orbiculoidea doria Hall.....	10
Rhipidomella vanuxemi Hall.....	13
Spirifer sp.	10
Stropheodonta demissa (Conrad).....	10
Stropheodonta hemispherica Hall.....	15
Stropheodonta perplana (Conrad).....	6, 13
Glyptodesma erectum (Conrad).....	6
Grammysia bisulcata (Conrad).....	6
Pterinea flabellum (?) (Conrad).....	6
Sphenotus cuneatus (Conrad).....	6
Platyceras erectum (Hall).....	6
Platyceras sp.	6
Tentaculites scalariformis Hall.....	3, 5, 6, 7

Delaware.—As far as the limestone is concerned, Delaware Run, at the point where it is crossed by the Hocking Valley Railroad, is the one important locality in this city. Campbell's quarry, on the east side of the railroad tracks, is the older of the quarries, and perhaps the more interesting since it has furnished the stone for the construction of many buildings in the city, and is the locality from which a number of types have been collected. The rock is much less shaly than is usual to the south, and contains but little chert. Near the west side of the quarry there is a fault having about six feet vertical displacement and passing to the south into a distributive fault of greater complexity. The line of fault (strike) runs nearly north and south.

The following section was measured along the southeast side:

		Ft.	In.
12.	Soil and drift	5	0
	Delaware limestone.		
11.	Thin bedded Crinoidal limestone having a grayish brown color	2	0
10.	Layer of fossiliferous grayish white chert	0	2
9.	Thin bedded more or less granular bluish limestone containing Crinoid fragments and *Hadrophyllum d'orbignyi.* (The Zone L of sections farther south)	2	0
8.	Thin bedded bluish gray to brown limestone	3	8
7.	Several layers of rather pure blue limestone	1	8
6.	Blue limestone with much bluish black chert imbedded in it	1	6
5.	Even bedded blue limestone in massive layers from four to twenty inches in thickness and containing very little chert	8	9
4.	Soft bluish limestone containing much white chert. The limestone weathers into a thin shaly clay-like mass releasing the chert	1	0
3.	Rather massive blue limestone in layers from six to fourteen inches thick and containing little or no chert	5	4
2.	Soft shaly blue limestone, very fossiliferous	0	6
1.	Two layers, each two feet, of blue limestone with a thin parting of soft shaly material much like No. 2	4	0

An attempt to locate, here as at Stratford, the various zones recognized further south, was not very successful, hence they have been omitted from the section in both cases. It seems quite probable, however, that the bottom of the quarry is not far above the "bone-bed" or top of the Columbus limestone.

The following species were found here:[1]

	Horizon.
Hadrophyllum d'orbignyi Edwards and Haime	9, 10
Orthopora regularis Hall	2
Orthopora sp.	2
Chonetes mucronatus Hall	2, 5
Chonostrophia reversa (Whitfield)	
Delthyris consobrina (d'Orbigny)	1, 2, 3, 4
Leiorhyhchus sp.	1
Leptæna rhomboidalis (Wilckens)	1, 3, 5
Spirifer macrus Hall	4
Tentaculites scalariformis Hall	2, 3, 4, 5
Onychodus sigmoides Newberry	3

In addition to these, fragments of plants and fish bones are commonly found. It was from this locality that many of Newberry's types were taken.

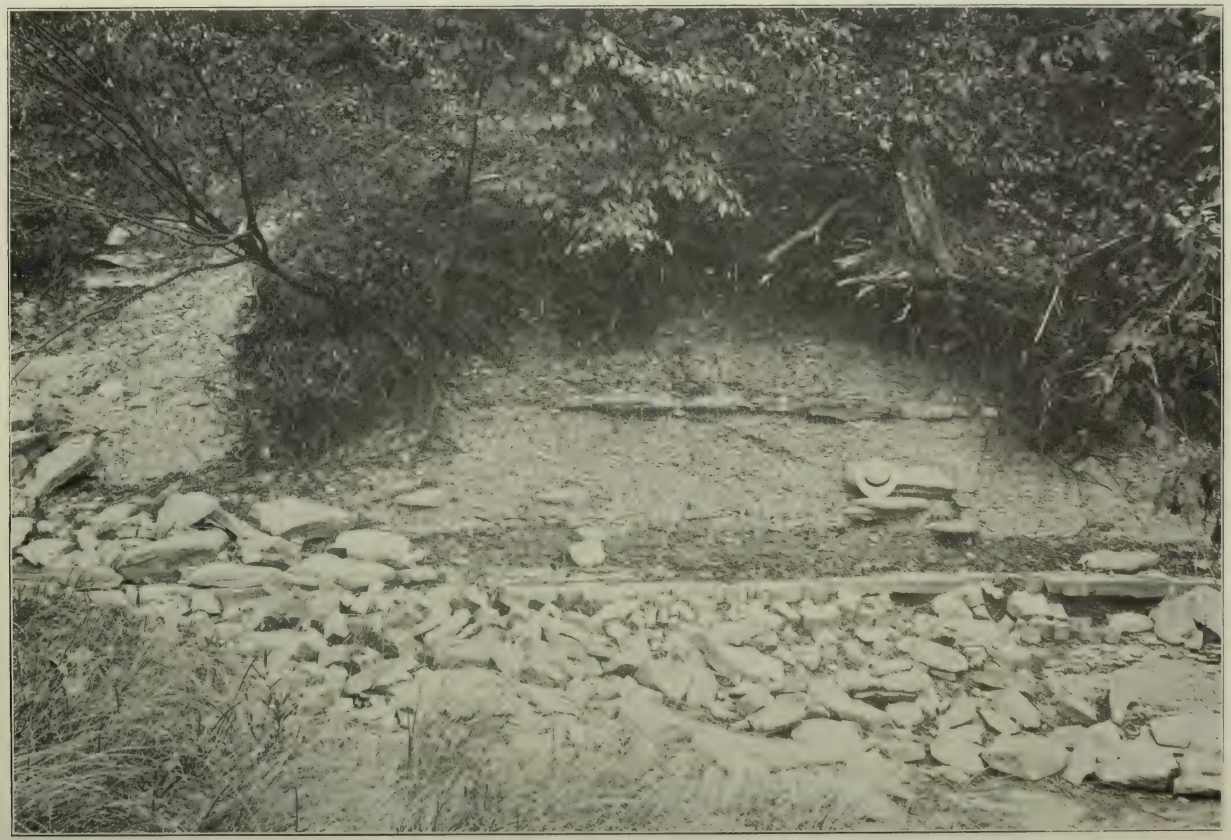
Another section at this city, of scarcely less importance, is the cliff of shale along the east bank of the Olentangy River a quarter of a mile below the Big Four Railroad bridge. This is Winchell's type section for the Olentangy shale (see Plate XII), since it is the one mentioned by him in naming the formation,[2] and a very exact section of which is given in connection therewith.

The following measurements were made towards the south end of the cliff:

		Ft.	In.
22.	Soil and drift	3	0
	Ohio shale.		
21.	Badly weathered and much altered black shale	8	0
20.	Black shale with some large more or less spherical concretions and some thin arenaceous layers at the contact below	22	0
	Olentangy shale.		
19.	Soft blue argillaceous shale	2	4
18.	Horizon of discontinuous layer of flat blue limestone concretions	..	..
17.	Soft argillaceous blue shale with a few thin layers of brown to black shale	5	4
16.	Soft argillaceous blue limestone	0	4
15.	Soft blue shale	1	4
14.	Brown to black shale with an occasional blue trail in it	0	4
13.	Argillaceous soft blue shale	1	0
12.	Layer of brown to black shale with blue trails	0	1
11.	Argilaceous soft blue shale	2	6
10.	Layer of brown shale with markings of blue	0	1

[1]See Dr. Bownocker's list of species collected and section of rocks at this locality. *Bull. Sci. Lab. Den. Univ.*, Vol. XI, 1898, pp. 22, 23, pl. IV.

[2]*Geol. Surv. Ohio*, Vol. II, pt. 1, 1874, pp. 284, 285, 287.



The Olentangy shale at N. H. Winchell's type section, along the east bank of the Olentangy River at Delaware. The illustration shows the layers of limestone and the flat concretions so common in the formation. These limestones contain a few poorly preserved fossils.

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		Ft.	In.
9.	Soft blue shale with a half dozen or more thin layers of argillaceous blue limestone, and an occasional flat limestone concretion near the base. Two feet seven inches above the base of this zone there is a remarkable bed of Crinoid fragments about midway along the cliff. It forms a lens of limestone with a maximum thickness of five inches and extends along the cliff for a distance of thirteen and one-half feet	4	10
8.	A persistent layer of flat limestone concretions	0	8
7.	Soft blue shale with an occasional flat disc-like concretion	1	6
6.	Persistent layer of disc-like concretions	0	4
5.	Soft argillaceous blue shale with several discontinuous layers of disc-like or flat concretions	3	0
4.	Rather definite layers of flat irregular limestone concretions	0	5
3.	Soft argillaceous blue shale with a few rather irregular blue limestone concretions	3	4
2.	Argillaceous blue limestone breaking with a very irregular and concoidal fracture	0	4
1.	Soft argillaceous blue shales tending to be massive, to level of Olentangy River	0	4

About a hundred yards down stream from the base of this section the Delaware limestone outcrops in the bottom of the river, the covered interval being probably three feet.

As usual with the Olentangy shale in central and southern Ohio, fossils are rare and in the main, poorly preserved. Aside from the local layer made up of Crinoid stems and fragments, included in No. 9 of the above section, the following fauna was collected:

Melocrinus sp.
Leiorhynchus sp.
Orbiculoidea sp.
Pleurotomaria sp.
Orthoceras sp.

As poor as this fauna is, and as scarce as the specimens are, it is still a fairly good forecast of the rather rich fauna of these beds to the north. While the specimens collected were hardly well enough preserved to admit of certain specific identification, they resemble very closely the species collected from the equivalent of this formation around Sandusky. Outcrops of the Olentangy shale are rare to the north, and its study has been attended with considerable difficulty and an appreciation of the necessarily unsatisfactory condition in which it must be left. Never-

theless, indications are strongly in favor of the interpretation here put upon the formation; namely, that it thickens materially on approaching the lake region, that it becomes quite fossiliferous, especially in the upper part, and that a limestone is introduced in its upper part and in contact with the overlying Huron shale. The Olentangy shale is thus the equivalent of at least the lower part of Newberry's "Prout limestone and marl." It may be well to state that on starting into the field, with a direct knowledge of only the Olentangy shale and a literature knowledge of the "Prout limestone and marl," exactly the opposite opinion was held, and only after a study of such outcrops of these two phases of the upper Hamilton, as may be found in the northern and central fields did the original conception become untenable.[1]

Waldo.—One of the most troublesome outcrops, and likewise one that is almost too poor to be considered, were good sections accessible, is to be found at the highway bridge across the Olentangy River one-half mile south of Waldo,[2] in the southern part of Marion county. Here the excavation for the east abutment of the iron bridge exposed some of the blue shales, while the calcareous layers are to be found in the bed of the river below the old dam, as well as along the west bank a short distance up stream. The east bank of the river above the dam gives an outcrop of Ohio shale which is scarcely five feet, by hand level, above the hard blue limestone (Delaware?) under the bridge. This would seem to indicate a considerable decrease in the thickness of the Olentangy shale at this point. However, the strata are here affected by small folds, as is the case farther south, and the exact interval is not known. In Crawford county Winchell gives the thickness of this formation as thirty feet,[3] but as there is no outcrop, its thickness may only be obtained from well sections while its fauna remains unknown.

Radnor.—The village of Radnor is located seven miles northwest of Delaware, and about three-quarters of a mile west of the Meredith station on the Hocking Valley Railroad. It is located on the eastern rim of the old drift filled valley of the Scioto. The group of quarries located near this place are the Delhi[4] quarries of Winchell's report. About a mile south of the village and a quarter of a mile west of the highway is the old Jones quarry. It has not been worked in recent years, nor was it ever opened to a very considerable depth, but the section is of interest in the discussion of these formations.

	Ft.	In.
3. Soil and drift	5	0

[1]But for Winchell's idea of the age of the Olentangy shale see *Proc. Am. Assoc. Adv. Sci.*, Vol. XXII, pt. 2, 1874, pp. 103, 104.

[2]See Winchell, N. H. *Geol. Surv. Ohio*, Vol. II, pt, 1, p. 287.

[3]*Idem*, p. 243. [4]*Idem*, p. 299

Columbus limestone.

	Ft.	In.
2. Rather compact gray limestone, very fossiliferous. This is probably a fairly massive rock, but it has weathered into thin beds	10	0
1. Compact slightly crystalline gray limestone containing some fossils, to bottom of the quarry	1	10

The following fauna was collected from this quarry:

	Horizon.
Favosites hemisphericus (Troost)	2
Zaphrentis cornicula Edwards and Haime	2
Zaphrentis gigantea Rafinesque	2
Atrypa reticularis (Linnæus)	1, 2
Rhipidomella vanuxemi Hall	2
Spirifer divaricatus Hall	2
Spirifer gregarius Clapp	2
Spirifer macrothyris Hall	2
Spirifer manni Hall	2
Spirifer sp.	1, 2
Stropheodonta demissa (Conrad)	2
Stropheodonta hemispherica Hall	1, 2
Stropheodonta perplana (Conrad)	2
Strophonella ampla Hall	2
Conocardium cuneus (Conrad)	1
Modiomorpha concentrica (Conrad)	1
Paracyclas elliptica Hall	1
Pleurotomaria lucina Hall	1
Gomphoceras plenum (Beecher)	1
Orthoceras sp.	1

Three-quarters of a mile farther south is the Meredith quarry, which has been opened on a larger scale and is still being worked. Here the following section was measured:

	Ft.	In.
4. Soil and drift	8	0

Columbus limestone.

3. Crystalline light gray limestone, very fossiliferous and especially full of *Spirifer gregarius.* Petroleum oozes from the cavities of the fossils. There can be no doubt but that this is Zone F of the general section	5	10
2. Compact to semi-crystalline gray limestone, fairly fossiliferous	8	6
1. Gray to brown limestone with very few fossils to the bottom of the quarry at the outlet of the spring	4	8

The following fauna was collected here:

	Horizon.
Calcisphæra robusta Williamson	3
Favosites hemisphericus (Troost)	2
Syringopora tabulata Edwards and Haime	2
Zaphrentis cornicula Edwards and Haime	3
Zaphrentis gigantea Rafinesque	2, 3
Zaphrentis sp.	3
Stromatopora ponderosa Nicholson	2
Stromatopora nodulata Nicholson	2
Stromatopora sp.	2
Cystodictya gilberti (Meek)	3
Atrypa reticularis (Linnæus)	1, 2, 3
Atrypa spinosa Hall	2
Chonetes mucronatus Hall	2, 3
Eunella lincklæni Hall	2
Leptæna rhomboidalis (Wilckens)	3
Pholidostrophia iowaensis (Owen)	2
Productella spinulicosta Hall	2
Rhipidomella vanuxemi Hall	2, 3
Schizophoria propinque Hall	2
Spirifer divaricatus Hall	2
Spirifer gregarius Clapp	2, 3
Spirifer macrothyris Hall	3
Spirifer manni Hall	2, 3
Stropheodonta demissa (Conrad)	1, 2, 3
Stropheodonta hemispherica Hall	2, 3
Stropheodonta perplana (Conrad)	1, 2
Strophonella ampla Hall	2
Conocardium cuneus (Conrad)	2, 3
Modiomorpha concentrica (Conrad)	1, 2
Murchisonia desiderata var. Hall	2
Pleurotomaria lucina Hall	2
Turbo shumardi Verneuil	3
Gyroceras cyclops Hall	2
Dalmantes sp.	3

This fauna shows the presence of Zones E and F of the general section, but the most interesting point here is the occurrence, in the bottom of the quarry, of a limestone which resembles Zone B, both in its paucity of fossils and its physical appearance. On top of these layers there is quite a representation of Corals, but no true Coral zone is visible anywhere. If these bottom layers belong in Zone B, then there is not only an absence of the chert and Coral zones, but a considerable lessening of the interval between Zones B and F, without any apparent indication of a break between the two.

Owen Station.—Along the Hocking Valley Railroad, five miles south of the city of Marion, Mr. Owen has a large quarry cutting both of the Devonian limestones. The rocks are somewhat folded, and have a strong dip to the southeast, bringing the *Spirifer gregarius* zone to the

This illustration shows the thick bedded character of the Delaware limestone in the east wall of Owen's quarry at Owen Station, Marion County. The camera case rests on the "bone-bed" or top of the Columbus limestone.

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surface at the west side of the quarry, while over eighteen feet of the Delaware is shown along the east side. (See Plate XIII). The full section of the quarry follows:

Delaware limestone.

		Ft.	In.
10.	Rather thin layers of blue limestone with much bluish white chert	5	0
9.	Massive and thin layers of blue limestone with some chert and usually shale partings which contain Crinoid stems	5	4
8.	Soft shaly blue limestone containing numerous Crinoid stems	1	0
7.	Thick even bedded blue limestone with shale and cherty partings	3	9
6.	Massive blue limestone in even beds	3	6

Columbus limestone.

5.	"Bone-bed" fairly well shown	..	..
4.	Massive bluish gray limestone not separable lithologically from that below and no smooth layer observed. (Zone H of the Central Ohio section)	10	0
3.	Massive bluish gray limestone in even beds, and containing numerous specimens of *Atrypa reticularis* and *Atrypa spinosa* near the top. (Corresponds to Zone G)	18	0
2.	Massive blue gray limestone limited above by a prominent ripple-marked bedding plane. *Spirifer gregarius* in abundance (Zone F)	2	6
1.	Very fossiliferous fine grained gray limestone, at places showing a blue cast. (Zone E)	14	6

The following species are quite plentiful at this place.

	Horizon.
Favosites emmonsi Rominger	4
Favosites hemisphericus (Troost)	4
Zaphrentis gigantea Rafinesque	1
Stromatopora ponderosa Nicholson	1
Nucleocrinus verneuili (Troost)	4
Cystodictya gilberti (Meek)	4, 6
Fenestella parallela (?) Hall	9
Atrypa reticularis (Linnæus)	1, 2, 3, 4
Atrypa spinosa Hall	3, 4
Camarotœchia tethys (Billings)	7
Chonetes mucronatus Hall	4, 6, 9
Chonostrophia reversa (Whitfield)	7
Delthyris consobrina (d'Orbigny)	7, 9, 10
Leptæna rhomboidalis (Wilckens)	7, 9
Productella spinulicosta Hall	6

	Horizon.
Rhipidomella vanuxemi Hall	4, 9
Schizophoria propinque Hall	4
Spirifer acuminatus (Conrad)	4
Spirifer duodenarius (Hall)	4
Spirifer gregarius Clapp	1, 2, 3
Spirifer macrus Hall	7
Stropheodonta concava (?) Hall	7
Stropheodonta hemispherica Hall	3, 4
Conocardium cuneus (Conrad)	1, 2, 3, 4
Bellerophon pelops Hall	2
Callonema lichas (Hall)	3
Palæotrochus kearneyi Hall	1
Platyceras bucculentum (?) Hall	6
Coleolus crenatocinctus Hall	1
Tentaculites scalariformis Hall	6, 9
Gyroceras cyclops Hall	1

This is an excellent place to study the two limestone phases of the Middle Devonian. The Columbus limestone is easily distinguished and compares very favorably with the same formation in Delaware and Franklin counties, even the zones being readily distinguishable. In general the rock is more massive and of a darker color, the blue predominating. It is a finer grained stone, and would probably make a superior building material were it not for the heavy bedding which makes it hard to work. The Delaware, on the other hand, differs decidedly even from that found at Campbell's quarry, to which its basal layers bear some resemblance. The lower part is a rather pure blue limestone, but the upper part contains much bluish white chert.

Marion.[1]—There are a number of quarries located in and around Marion. Most of them are located north and west of the city, and the larger ones are grouped along the Hocking Valley Railroad tracks about a mile northwest of the Union station. The first quarry of the group lying on the east side of the tracks, is the John Evans quarry, while that just across the tracks to the west is the Norris and Christian quarry. The rocks dip rather sharply to the east, so that the former of these quarries contains much more of the Delaware limestone, while the latter has a greater opening in the Columbus limestone.

The combined measurements of these two quarries give the following section:

Delaware limestone.

		Ft.	In.
13.	Granular Crinoidal blue limestone	3	0
12.	Bluish brown limestone in rather thin even layers alternating with a great quantity of soft bluish white chert. The chert contains Bryozoans	12	6

[1]See also Swartz, Charles K. *Op. cit.* p. 61.

		Ft.	In.
11.	Rather massive layers of blue limestone with pockets of fossiliferous white chert and thin shaly partings	9	6
10.	Soft shaly blue limestone	0	6
9.	Massive blue limestone with some chert and shaly partings	5	6

Columbus limestone.

8.	"Bone-bed"	..	..
7.	Fossiliferous gray limestone	2	0
6.	Layer of Crinoidal gray limestone	2	0
5.	Massive gray limestone, somewhat Crinoidal and very fossiliferous	10	0
4.	Layer of hard gray chert alternating with gray limestone, both fossiliferous	4	0
3.	Massive gray limestone at places crowded with specimens of *Atrypa spinosa* and *Atrypa reticularis*	3	0
2.	Massive layers of very fossiliferous light gray limestone	12	6
1.	Massive gray to light brown limestone, sparingly fossiliferous, to bottom of quarry	8	6

In making the following collection of species, more attention was given to the Delaware limestone, since it is the greater variable. The collection from the Columbus limestone can hardly be considered as representative.

	Horizon.
Calcisphæra robusta Williamson	5
Favosites hemisphericus (Troost)	3
Syringopora tabulata Edwards and Haime	4
Zaphrentis cornicula Edwards and Haime	3
Stromatopora ponderosa Nicholson	3
Cystodictya gilberti Meek	9, 10, 12, 13
Fenestella sp.	11, 12
Atrypa reticularis (Linnæus)	3, 5, 10
Atrypa spinosa Hall	3, 5
Camarotœchia billingsi Hall	9
Chonetes deflectus Hall	10
Chonetes mucronatus Hall	5, 9
Chonetes sp.	9, 11
Cyrtina hamiltonensis Hall	10, 13
Delthyris consobrina (d'Orbigny)	9, 11, 12, 13
Leptæna rhomboidalis (Wilckens)	9, 10, 11
Orthothetes pandora (Billings)	10
Pentamerella arata (Conrad)	5
Pholidostrophia iowaensis (Owen)	13
Productella spinulicosta Hall	9, 10
Rhipidomella vanuxemi Hall	11
Rhipidomella sp.	9, 11, 12, 13
Schizophoria propinque Hall	5

	Horizon.
Spirifer acuminatus (Conrad)	4, 5
Spirifer duodenarius (Hall)	7
Spirifer gregarius Clapp	2
Spirifer sp.	5, 10
Stropheodonta concava Hall	13
Stropheodonta demissa (Conrad)	9, 11, 13
Stropheodonta hemispherica Hall	3, 5
Stropheodonta sp.	5, 13
Conocardium cuneus (Conrad)	5
Bellerophon sp.	13
Platyceras carinatum Hall	10
Platyceras dumosum Conrad	4
Platyceras nodosum Conrad	12
Platyceras sp.	9
Pleurotomaria sp.	13
Tentaculites scalariformis Hall	9, 10, 11, 12
Gyroceras cyclops Hall	2
Gyroceras sp.	5, 13
Phacops sp.	13

About a mile and a half northeast of this group of quarries, there is another group which is located along the Pennsylvania Railroad tracks. The larger of these openings is the Central Ohio quarry, of which the following is a section:

	Ft.	In.
7. Soil and drift	6	0

Columbus limestone.

	Ft.	In.
6. Rather massive bluish gray to brown fossiliferous limestone	1	2
5. Bluish gray limestone with quite a number of fish bones and teeth in the upper part, but in general with few fossils	2	10
4. Layer of *Diphyphyllum verneuilanum*	0	3
3. Massive crystalline bluish gray limestone, very fossiliferous	10	6
2. Bluish earthy limestone with a great quantity of white chert and containing very few fossils	4	0
1. Massive bluish gray limestone. This portion is very fossiliferous and contains great numbers of *Atrypa reticularis* in the upper part	10	4

The following fauna is a very fair representative of that which is to be found here:

	Horizon.
Calcisphæra robusta Williamson	1, 3
Cystiphyllum vesiculosum Goldfuss	6
Diphyphyllum verneuilanum (Edwards and Haime)	4

	Horizon.
Diphyphyllum sp.	1
Favosites hemisphericus (Troost)	3
Stylastrea anna Whitfield	1
Syringopora tabulata Edwards and Haime	1
Zaphrentis cornicula (Edwards and Haime)	1, 3
Zaphrentis prolifica Billings	3
Zaphrentis sp.	1, 2, 3
Stromatopora sp.	1
Cystodictya gilberti (Meek)	3
Atrypa reticularis (Linnæus)	1, 3
Chonetes mucronatus Hall	1, 3
Leptæna rhomboidalis (Wilckens)	6
Orthothetes pandora (Wilckens)	3
Pentamerella arata (Conrad)	3
Productella spinulicosta Hall	3
Rhipidomella vanuxemi Hall	1, 3
Spirifer acuminatus (Conrad)	3
Spirifer duodenarius (Hall)	6
Spirifer manni Hall	3
Spirifer sp.	3
Stropheodonta demissa (Conrad)	1, 3
Stropheodonta hemispherica Hall	1, 3
Stropheodonta perplana (Conrad)	1, 3
Conocardium cuneus (Conrad)	1
Paracyclas elliptica Hall	3
Loxonema sp.	3
Pleurotomaria sp.	3
Gomphoceras sp.	1

This section extends practically to the top of the Columbus limestone. A short distance to the north of the Central Ohio quarry is the Hamilton quarry, in which a portion of the lower part of the Delaware limestone is exposed. The dividing line between the two formations is not always clear in this region, since at many places they seem to grade into each other. But the doubtful portion (No. 6 of above section) never exceeds two feet, and since it contains an occasional specimen of *Spirifer duodenarius*, it is referred to the Columbus limestone.

The quarries at Marion still produce a considerable quantity of lime. This is the southernmost locality at which the Columbus limestone is being burned on a large scale, except at White Sulphur, west of Delaware, where some is still produced. The industry, however, is on the decline throughout the central part of the state, as is evidenced by the abandonment of the kilns and the introduction of crushers in some of the large quarries where none were in use a short time ago. Within the last few years the kilns of some of the large Marion quarries have been abandoned, while others are seldom used. Such has been the history of the lime industry all over that portion of the state where the Devonian limestones have been employed, and probably will be even at Marble-

8—S. G.—1,000.

head and Kelley's Island, the greatest stronghold of the industry as connected with these formations. The rock makes a superior lime, although it air-slacks readily, and thus its shipping qualities are depreciated; but the increasing demand for crushed rock is requiring nearly the entire output of these quarries, except that used for building purposes and for furnace flux.

It has been noted that at Marion and Owen Station the rock strata are thrown into broad low anticlinal and synclinal folds. The axes of these folds have, in general, a westerly trend, and possibly tie up with the Shelby-Akron arch.[1] In addition there has been an upwarp of the entire region, so that here the "bone-bed" lies two hundred feet higher than at Columbus, and over three hundred feet higher than at Sandusky. The Bellefontaine outlier is believed to be an expression of this same disturbance and not necessarily a remnant which indicates the former crossing of this portion of the Cincinnati arch by these formations, for Lima and Findlay are probably at the summit of the axis. Under this interpretation it is perhaps proper to treat this outlier here in connection with the central strip to which it is more closely related.

Cable.—This village is located on the Pennsylviana Railroad, ten miles northeast of Urbana, Champaign county. A short distance south of the Pennsylvania Railroad tracks and scarcely a mile southwest of Cable station, is a small quarry, the southernmost known outcrop of the Devonian outlier. The section here, and along the run which passes through the pit, is as follows:

Columbus limestone.

	Ft.	In.
6. Massive, very fossiliferous gray limestone The stone is very much weathered.....	3	0
5. Massive and thin layers of bluish gray limestone much weathered and at places partly covered	14	0
4. Fairly massive brown limestone containing much fossiliferous gray or white chert.	3	0
3. Compact grayish brown limestone, thin bedded and somewhat banded.....	2	4
2. Layer of arenaceous gray limestone.....	0	10

Monroe formation.

1. Thin bedded hard compact drab limestone with a laminated structure. This extends to the lower part of the run near the highway, where it goes under cover	10	8

[1]Orton, Edward, *Geol. Surv. Ohio*, Vol. VI, 1888, pp. 57, 58.

Fauna of above section:

	Horizon.
Calcisphæra robusta Williamson	6
Diphyphyllum sp.	4
Favosites goldfussi d'Orbigny	4
Favosites hemisphericus (Troost)	6
Pleurodictyum problematicum Goldfuss	4
Zaphrentis cornicula Edwards and Haime	6
Cystodictya gilberti (Meek)	6
Cystodictya sp.	4
Fenestella sp.	4
Amphigenia elongata (?) (Vanuxem)	4
Atrypa reticularis (Linnæus)	6
Atrypa spinosa Hall	6
Camarospira eucharis Hall	4
Eunella sp.	4
Metaplasia disparalis Hall	4
Meristella sp.	5
Orthothetes pandora (Billings)	4
Pholidostrophia iowaensis (Owen)	6
Spirifer divaricatus Hall	4
Spirifer gregarius Clapp	6
Spirifer sp.	4, 6
Strophalosia cf. truncata Hall	4
Stropheodonta demissa (Conrad)	6
Stropheodonta hemispherica Hall	6
Stropheodonta inæquiradiata Hall	6
Stropheodonta parva (?) Hall	4
Stropheodonta perplana (Conrad)	4
Actinopteria boydi (Conrad)	6
Conocardium cuneus (Conrad)	6
Paracyclas elliptica Hall	6
Schizodus contractus Hall	6
Schizodus tumidus Hall	6
Bellerophon pelops Hall	6
Dentalium martini Whitfield	6
Loxonema pexatum Hall	4, 6
Murchisonia desiderata Hall	6
Murchisonia maia Hall	4
Platyceras sp.	4
Pleurotomaria lucina Hall	6
Pleurotomaria sp.	4
Coleolus crenatocinctus Hall	6
Odontocephalus ægeria Hall	4
Phacops cristata Hall	6
Proetus crassimarginatus Hall	4

This section is of importance because of its rather extensive fauna, and because of the diminished thickness of the lower or sparingly fossiliferous part of the Columbus limestone. No. 6 of the section given above is very fossiliferous, and the most abundant species is *Spirifer gregarius*. Whether this is the same zone (Zone F) that has been noticed in the

vicinity of Columbus, is perhaps not determinable, but it carries a fauna which supports that view. The arenaceous layer, No. 2 of the section, might perhaps be called a sandstone. Sand is a common constituent of the limestones of this region[1] and its presence, even at the base of the formation, is probably of no special geological significance except as a possible indication of land conditions near by. The Cable region was mapped as Silurian by the earlier Survey, and apparently the drift is immediately underlain by that system in the greater part of it. The outcrop here discussed is doubtless but a detached fragment of the great outlier to the north.

West Liberty.—This place is located on the Big Four Railroad, and also on the electric line, about twelve miles south of Bellefontaine. There are many outcrops of Devonian limestone to the east of town, but none of them are extensive. The Gen. Piatt quarry is the most interesting and also the most important opening made in the rocks of this locality. It was from the lower part of this quarry that the stone was taken for the construction of the "Castle" in which the General resides, as well as for the son's mansion, and for the beautiful new school building in West Liberty. The building stone, however, is Monroe limestone. The quarry is located two miles east of town on lands now occupied by Mrs. Frances Piatt, and has the following section:

Columbus limestone.

	Ft.	In.
6. Very fossiliferous gray limestone. The lower part is a conglomerate composed of Monroe limestone pebbles imbedded in the gray limestone	2	4

Monroe limestone.

5. Compact hard drab limestone containing such Corals and *Meristelloid* Brachiopods as occur in the upper part of the Silurian at Sandusky	1	8
4. Rather massive, somewhat banded gray limestone showing a tendency to split into thin uneven layers. Unfossiliferous	5	0
3. Massive layer of gray banded fine grained limestone without fossils	12	0
2. Massive gray limestone, banded and rather fine grained. Hackel-toothed upper surface. Unfossiliferous	2	5
1. Massive layer of brown limestone banded with darker brown. Unfossiliferous	4	7

[1]*Geol. Surv. Ohio*, Vol. III, 1878, pp. 485, 486.

The fauna of the top of the Monroe was considered only to make certain that it is Silurian. The following is the Devonian fauna from the top layers of the quarry.

	Horizon.
Calcisphæra robusta Williamson	6
Favosites hemisphericus (Troost)	6
Stylastrea anna Whitfield	6
Zaphrentis cornicula Edwards and Haime	6
Atrypa reticularis (Linnæus)	6
Atrypa spinosa Hall	6
Chonetes mucronatus Hall	6
Eunella lincklæni Hall	6
Nucleospira concinna Hall	6
Pholidostrophia iowaensis (Owen)	6
Stropheodonta hemispherica Hall	6
Spirifer gregarius Clapp	6
Conocardium cuneus (Conrad)	6
Paracyclas elliptica Hall	6
Schizodus tumidus Hall	6
Callonema cf. bellatulum (Hall)	6
Euomphalus decewi Billings	6

This is the same fauna as that collected from No. 6 of the Cable section, and is doubtless contemporaneous with it. Here, however, it rests directly on the Silurian limestone.

Bellefontaine.—On the west side of this city the Bellefontaine Stone and Lime Company has quarried extensively in the Columbus limestone. The sections of the various pits are essentially the same, the following being that of the east opening.

Columbus limestone.

		Ft.	In.
7.	Thin weathered layers of gray limestone	5	0
6.	Massive porous layers containing Corals and Brachiopods	3	0
5.	Massive and thin bedded gray to drab dolomitic limestone not in even courses. Fossils rare and those that do occur are in the form of moulds. Some pockets of white chert	11	8
4.	Gray limestone with pockets of fossiliferous white chalky chert	0	6
3.	Two massive layers of dark gray to brown limestone with some chert	4	8
2.	More or less pockety fossiliferous white chalky chert	0	2
1.	Layers of from four to eight inches of a yellowish gray banded to drab limestone. Some brecciated layers and a little chert extending to the water level in the deepest part of quarry	4	0

The white cherts are usually full of fossils, but the limestone contains few, and those but poorly preserved.

Following is the fauna collected here.[1]

	Horizon.
Favosites emmonsi Rominger	6
Favosites hemisphericus (Troost)	6
Zaphrentis sp.	6
Cystodictya gilberti (Meek)	2
Fenestella sp.	2
Atrypa reticularis (Linnæus)	6
Athyris vittata indianaensis n. var	2
Camarotœchia tethys (Billings)	2
Chonetes deflectus Hall	2
Chonetes mucronatus Hall	2
Cyrtina hamiltonensis Hall	2
Pholidostrophia iowaensis (Owen)	2, 6
Rhipidomella vanuxemi Hall	2, 6
Spirifer acuminatus (Conrad)	2, 4
Spirifer sp.	2
Stropheodonta demissa (Conrad)	2
Stropheodonta hemispherica Hall	2, 5, 6
Stropheodonta perplana (Conrad)	2
Strophonella ampla (?) Hall	5
Glyptodesma occidentale Hall	2
Modiomorpha concentrica (?) (Conrad)	6
Bellerophon newberryi Meek	2
Naticopsis lævis (?) Meek	2
Platyceras dumosum Conrad	2
Platyceras sp.	2
Pleurotomaria sp.	6
Trochonema meekanum Miller	5
Coleolus crenatocinctus (?) Hall	5
Tentaculites scalariformis Hall	2

The bottom of this quarry is probably well down towards the top of the Silurian. This seems apparent from the outcrop of Monroe limestone in the quarry at Big Springs, two miles northeast of Rushsylvania, where the top layers along the west side of the quarry are composed of a similar rock. Fish teeth and dermal plates are frequently found in these quarries, but no "bone-bed." In fact there is no natural dividing line between the lower deposits, which are surely Columbus limestone, and those above that may be Delaware in this whole outlier. There is a gradual transition upward into more and more arenaceous beds, and finally the abrupt change to the Ohio shale without the intervention of the Olentangy shale.

Zanesfield.—These upper layers are well shown at the George Grubb quarry, in the southern part of the town of Zanesfield, six miles

[1]See Dr. Bownocker's list. *Bull. Sci. Lab. Den. Univ.*, Vol. XI, 1898, pp. 35, 36, 37.

southeast of Bellefontaine, and along a small run across the highway to the north. The following is the section along the run at this place:

Ohio shale.

		Ft.	In.
5.	Black shale, as much as a hundred feet exposed along the road	4	0
4.	Covered interval which north of this locality was found to be Ohio black shale	5	0

(*Possibly Delaware Limestone.*)

3.	Six to eight-inch layers of hard arenaceous blue limestone with very few fossils	11	0
2.	Arenaceous gray limestone with some fossiliferous gray to white chert	1	2
1.	Hard arenaceous gray limestone in six to eight inch beds to bottom of outcrop	6	0

And in the Grubb quarry the following rocks are uncovered:

(*Possibly Delaware limestone.*)

		Ft.	In.
10.	Massive gray limestone, hard and silicious	4	0
9.	Gray to white banded chert	0	3
8.	Massive gray limestone, hard and silicious	4	8
7.	Massive gray limestone containing moulds of Corals	1	9
6.	Fossiliferous gray chert	0	4
5.	Thin bedded gray limestone with a reddish cast. Contains some Corals	1	8

(*Probably Columbus limestone.*)

4.	Gray limestone with some fossils and containing a considerable amount of chert	2	6
3.	Massive gray limestone with some white chert	2	0
2.	Covered with waste from the quarry	3	8
1.	Fossiliferous gray limestone forming the base of the old quarry	1	6

The fossils in the rocks of this section are too poorly preserved for positive identification, but in addition to a few Corals, Crinoid stems and Bryozoans, the following genera were recognized in this quarry: *Rhipidomella, Dentalium, Loxonema* and *Pleurotomaria.*

East Liberty is located four miles east of Zanesfield, on the Toledo and Ohio Central Railroad, and about ten miles southeast of Bellefontaine, in Logan county. There are several quarries to the west of this

place, but the one furnishing the most interesting section is to be found on the Armstrong farm one mile and a quarter northwest of town. In a small run just south of the house some quarrying has been done, and the following section is there exposed:

Delaware limestone (??).

		Ft.	In.
8.	Very hard pyritiferous layers of crystalline blue limestone containing some fish teeth and Crinoid stems. The Ohio shale is not exposed here, but these layers are probably those lying immediately below it, where the two formations are seen together	10	0
7.	Rather thin layers of grayish or brown limestone with some chert, few fossils and much iron pyrites	14	8
6.	Bluish gray limestone alternating with layers of gray somewhat chalky chert	3	2
5.	Bluish gray even bedded limestone and containing little or no chert	3	8
4.	Massive layer of Crinoidal gray limestone containing a number of Corals. The fresh surface of this rock shows a reddish cast	2	3

Columbus limestone.

3.	Massive bluish gray hard crystalline limestone, sparingly fossiliferous	5	4
2.	Layer of gray limestone containing some fossils	2	0
1.	Rough hard limestone forming the lowest part of the outcrop in the bed of the run	2	0

In this quarry also no clear distinction between the lower and upper limestones is possible, for the upper portion is so poor in fossils, and so far has yielded none that are distinctively Delaware, that the basis for division is completely gone. The total thickness of the Devonian limestone strata of the Bellefontaine outlier was not definitely determined, but a combination of sections seems to indicate that it probably does not greatly exceed "one hundred feet."[1] Probably the whole deposit should be called Columbus limestone, the Delaware being absent, as is its kindred formation, the Olentangy shale.

Among the poorly preserved fossils, the few that were collected and are recognizable are:

	Horizon.
Favosites hemisphericus (Troost)	3
Zaphrentis sp.	6
Atrypa reticularis (Linnæus)	3
Rhipidomella sp.	6

[1]Hill, Franklin C., *Geol. Surv. Ohio*, Vol. III, 1878, p. 485

	Horizon.
Stropheodonta hemispherica Hall	6
Spirifer acuminatus (Conrad)	3
Spirifer sp.	6
Trochonema meekanum Miller	6

On the adjoining farm to the east Mr. Bell has opened a small quarry just west of his house, where the following section is exposed:

Columbus limestone.

		Ft.	In.
5.	Scattered outcrops of grayish brown limestone with a little chert. This portion is shown along the run above the quarry	9	0
4.	Chert and cherty limestone forming the top layer in the old quarry	0	6
3.	Layer of porous brown limestone	1	0
2.	A layer consisting mostly of chert and cherty limestone	0	8
1.	Massive light brown, rather porous limestone with irregular bedding. Quite fossiliferous, but the fossils are poorly preserved and generally in the form of moulds	13	8

The following is the fauna of the lowest division of the section:

Calcisphæra robusta Williamson
Favosites hemisphericus (Troost)
Stylastrea anna Whitfield
Zaphrentis cornicula Edwards and Haime
Stromatopora ponderosa Nicholson
Cystodictya gilberti (Meek)
Fenestella sp.
Atrypa reticularis (Linnæus)
Atrypa spinosa Hall
Chonetes mucronatus Hall
Cyrtina hamiltonensis Hall
Nucleospira concinna Hall
Spirifer gregarius Clapp
Stropheodonta demissa (Conrad)
Stropheodonta hemispherica Hall
Paracyclas elliptica Hall
Bellerophon pelops (?) Hall
Callonema bellatulum Hall
Dentalium martini Whitfield
Pleurotomaria sp.
Tentaculites scalariformis Hall

In addition to these, Crinoid stems are to be found, but they are a common constituent of the fossiliferous portion of the Columbus limestone everywhere. This fauna is so similar to the Cable fauna as to sug-

gest that it is below the middle of the formation. The section certainly lies below that given for the Armstrong quarry, and probably below or at the horizon of the very bottom of the East Liberty Stone Company's quarry, which is located along the railroad a mile west of the East Liberty depot, and a section of which follows:

Columbus limestone.

	Ft.	In.
3. Thin bedded and massive layers of grayish brown limestone containing some chert and few fossils except moulds of Corals	24	0
2. Gray limestone alternating with layers of grayish white chert	3	10
1. Massive gray or grayish brown limestone with very little chert. Fossils more plentiful than in other parts of the quarry, but still rare	11	2

In the lower part of the quarry only a few fossils were collected, and among these the identifiable ones are: *Favosites hemisphericus, Stropheodonta demissa, Stropheodonta hemispherica* and *Platyceras dumosum.*

The basal portion of this quarry is not so fossiliferous as is the lower part of the section on the Bell farm, but the lithological structure is much the same, and the few fossils that do occur are not adverse to the view that they are possibly at the same horizon.

Middleburg.—The town of Middleburg is located in the northern part of Zane township, and about two and one-half miles south of East Liberty. The old quarry located in the northern edge of the village is the Sharpe quarry of the early survey and is still known by that name, although no longer worked. Here the following section is exposed:

Columbus limestone.

	Ft.	In.
7. Gray to brown rather thin bedded limestone	1	8
6. Chalky and hard white chert, very fossiliferous	0	3
5. Very fossiliferous gray limestone, containing *Calcisphæra robusta* in great numbers	2	10
4. Layer of grayish brown hard limestone with some chert at the base	1	8
3. Gray limestone, probably massive but weathered into thin layers. Quite fossiliferous	4	0
2. Two rather massive layers of gray limestone showing a reddish cast, the weathered surface often brick red. The upper surface is stylolitic and ochreous. The two layers are separated by an inch or two of chert	5	4

	Ft.	In.
1. Massive gray to brown limestone quite fossiliferous. *Calcisphæra robusta, Favosites hemisphericus*, etc., common. (The layer bears a striking resemblance to the "Bottom rock" of Marblehead and Kelley's Island quarries)	7	9

This is one of the most interesting localities, and perhaps the best collecting ground of the Bellefontaine region.

The following species are from this quarry:

	Horizon.
Calcisphæra robusta Williamson	1, 5, 6
Favosites hemisphericus (Troost)	1
Stylastrea anna Whitfield	5
Syringopora tabulata Edwards and Haime	5
Fenestella sp.	5
Athyris vittata indianaensis n. var	5
Atrypa reticularis (Linnæus)	1, 5
Atrypa spinosa Hall	5
Chonetes mucronatus Hall	5
Cyrtina hamiltonensis Hall	6
Nucleospira concinna Hall	5
Pentamerella arata (Conrad)	6
Pholidostrophia iowaensis (Owen)	6
Rhipidomella sp.	5
Spirifer acuminatus (Conrad)	5
Spirifer duodenarius (Hall)	5
Spirifer gregarius Clapp	5
Stropheodonta demissa (Conrad)	3, 5, 6
Stropheodonta hemispherica Hall	1, 2, 5
Stropheodonta perplana (Conrad)	6
Actinopteria boydi (Conrad)	6
Conocardium cuneus (Conrad)	5, 6
Bellerophon acutilira (?) Hall	6
Callonema lichas (Hall)	6
Cyclonema sp.	5
Loxonema pexatum Hall	6
Loxonema sicula (?) Hall	6
Coleolus crenatocinctus Hall	5
Chasmops calypso Hall	6
Phacops cristata Hall	5, 6

The horizon of this section is probably about that of the Bell quarry, and consequently well down towards the base of the formation, but lithologically and structurally it stands alone—at least so far as outcrops seen are concerned.

Rushsylvania.—This village is located along the Big Four Railroad ten miles northeast of Bellefontaine. One and one-half miles east

of here, Mr. Peter Roberts has opened a quarry just south of his barn, where the following section is exposed.

Columbus limestone.

		Ft.	In.
11.	Thin bedded arenaceous gray limestone....	2	0
10.	Covered interval	0	6
9.	Layers of thin bedded arenaceous gray limestone with pockets of chert. Contains some Corals	8	2
8.	Hard crystalline gray limestone, red with iron and containing some gray chert. All much weathered	8	4
7.	Massive fossiliferous gray limestone. Common fossils are *Atrypa reticularis, Atrypa spinosa, Rhipidomella vanuxemi, Stropheodonta hemispherica,* etc.	2	2
6.	Hard crystalline blue limestone containing much chert and showing deep stylolitic structure. Contains *Rhipidomella vanuxemi*	2	8
5.	Two layers of hard gray limestone in which no fossils were seen.....	1	8
4.	Massive compact gray limestone in two layers. Among other Corals, *Favosites emmonsi* was recognized.....	3	0
3.	Soft porous gray limestone becoming hard when exposed to the air.....	0	10
2.	Two eighteen-inch layers of gray limestone with some chert between.....	3	0

Monroe limestone.

1.	Compact drab banded limestone, rather massive	3	0

Nearly seven feet of this section was covered with water, but Mr. Roberts kindly furnished the measurements for Nos. 1, 2 and 3, and pointed out blocks of each that had been quarried and were then lying in the higher part of the quarry. Fossils are not abundant in the rock here, but careful collecting would give a much more extensive fauna than the few mentioned in the above section. The section may be compared with that of the Sharpe quarry at Middleburg, since they probably both belong to the same horizon, except that the Roberts quarry extends downward into the Monroe limestone.

A careful consideration of these sections, taken at various points over the Bellefontaine outlier as compared with sections of the similar horizon in the central part of the state, brings out the following facts: (*a*) The lower comparatively unfossiliferous portion of the Columbus

limestone has been somewhat reduced in thickness, or may be wanting entirely, as at the Gen. Piatt quarry. (*b*) In general the fossiliferous portion contains fewer specimens, and all are rather poorly preserved. (*c*) The upper portion of the Devonian limestone is arenaceous and very impure, but it resembles the Delaware limestone neither in composition and structure nor in its fauna. (*d*) There is neither a "bone-bed" nor any other recognizable horizon marker dividing the limestone into two formations, and probably no such division should be made. (*e*) The Olentangy shale is wanting, the Ohio shale resting directly upon the limestone. (*f*) So far as the fauna goes then, there is an hiatus of the entire Hamilton period. It is probable that this deposit represents the off-shore conditions of the earlier Middle Devonian, and that during the latter part the sea had retreated eastward not to return until the black shale conditions were inaugurated. The Devonian hills of the Bellefontaine region are sometimes called "the Summit of the State," since they contain its greatest elevation above tide. The angle of the dip of the rocks is low and in various directions, but it is probable that the elevation of this portion of the formation relative to other portions has changed very materially since its original deposition.

Bucyrus.—The outcrops near this place are west of the city and mostly along Broken Sword Creek. The best of these, and also the most accessible, is in the quarry of the Broken Sword Stone Company, at Spore, six miles northwest of Bucyrus on the Toledo and Ohio Central Railroad. Here the following section is exposed:

Delaware limestone.

		Ft.	In.
12.	Hard blue limestone, containing a great many specimens of *Delthyris consobrina*, *Leptæna rhomboidalis*, etc	1	8
11.	Soft blue shaly limestone containing many Crinoid stems and various trails	0	3
10.	Thin bedded and rather massive layers of very hard blue limestone	2	6
9.	Soft blue shaly parting	0	1
8.	Hard blue limestone in layers from three to six inches thick and quite fossiliferous	3	8
7.	More or less granular bluish gray limestone containing many Corals and Crinoid stems	0	10

Columbus limestone.

6.	"Bone-bed," best developed along the east side of the quarry	..	..
5.	Thin bedded blue limestone containing an abundance of *Spirifer duodenarius*	2	8

	Ft.	In.
4. Very fossiliferous gray limestone, rather massive but splitting into thin layers....	10	8
3. Rather massive gray limestone which is very fossiliferous. *Stropheodonta* and *Rhipidomella* are the predominating genera..	4	0
2. Compact very hard bluish gray limestone with some chert and few fossils.....	4	0
1. Crystalline gray limestone with much petroleum	3	0

The limestones are remarkably free from chert. The fauna, while rich in individuals, is comparatively poor in species. The following is a fair representation of the fauna here:

	Horizon.
Calcisphæra robusta Williamson.....	1, 3, 4
Diphyphyllum verneuilanum (Edwards and Haime)..	5
Favosites hemisphericus (Troost).....	1, 3, 4
Heliophyllum sp.	7
Stylastrea anna Whitfield.....	4
Syringopora tabulata Edwards and Haime.....	2
Zaphrentis cornicula Edwards and Haime.....	3, 4
Zaphrentis sp.	2, 5
Cystodictya gilberti (Meek).....	4
Fenestella sp.	4
Monotrypa tenuis (Hall).....	4
Atrypa reticularis (Linnæus).....	2, 3, 4, 5, 12
Atrypa spinosa Hall.....	1
Camarotœchia carolina Hall.....	4
Camarotœchia sp.	5
Chonetes mucronatus Hall.....	3, 4
Chonetes scitulus Hall.....	12
Cyrtina hamiltonensis Hall.....	8
Delthyris consobrina (d'Orbignyi).....	8, 10, 12
Eunella lincklæni Hall.....	2, 12
Leptæna rhomboidalis (Wilckens).....	4, 5, 8, 10, 12
Orthothetes pandora (Billings).....	4
Rhipidomella vanuxemi Hall.....	3, 4, 12
Spirifer duodenarius (Hall)	5
Spirifer macrus Hall.....	4
Stropheodonta demissa (Conrad).....	1, 2, 3, 4, 12
Stropheodonta hemispherica Hall.....	3, 4, 5, 10
Stropheodonta perplana (Conrad).....	3, 4, 5
Strophonella ampla Hall.....	1
Conocardium cuneus (Conrad).....	4
Paracyclas elliptica Hall.....	10
Platyceras erectum Hall.....	8
Phacops sp.	5

Bloomville.—This town is located on the Pennsylvania lines, ten miles southeast of Tiffin. To the east and north of this place several small openings have been made for quarrying purposes, and the lime-

stone also outcrops along the streams, but by far the most important is the France quarry, one and one-half miles east of town, where the following section may be found:

Delaware limestone.

		Ft.	In.
11.	Compact blue Crinoidal limestone	2	0
10.	Bluish gray limestone containing a good many Corals and Blastoids. The most important Coral is *Cystiphyllum vesiculosum*	2	0
9.	Rather massive bluish gray limestone splitting unevenly when quarried. This portion is very fossiliferous	5	0
8.	Blue to brown limestone containing a small amount of chert	2	4
7.	Impure blue limestone with much white chert. The chert runs through the limestone in all directions like ropes. Sometimes there is a parting of blue shale between layers and this is often full of fossils	12	4
6.	Massive layer of Crinoidal blue limestone	1	6
5.	Shaly blue limestone parting	0	1
4.	Massive layer of Crinoidal blue limestone	1	6
3.	Bluish black shale parting	0	1
2.	Six-inch layer of blue limestone with shale partings	2	0

Columbus limestone.

1.	Massive blue limestone, very fossiliferous	5	6

At this place the Delaware limestone is quite fossiliferous and especially so in the upper part. The following fauna was collected from this section:

	Horizon.
Cystiphyllum vesiculosum Goldfuss	10
Zaphrentis sp.	10
Nucleocrinus venustus (?) Miller and Gurley	10
Cystodictya gilberti (Meek)	2, 7, 9
Fenestella sp.	1, 2
Trematopora sp.	2
Atrypa reticularis (Linnæus)	2, 9, 10
Atrypa spinosa Hall	1, 9
Camarotœchia billingsi Hall	9
Camarotœchia tethys (Billings)	9
Camarotœchia sp.	1, 10
Chonetes mucronatus Hall	1, 9
Chonetes scitulus Hall	7
Chonetes sp.	2, 7, 10
Chonostrophia reversa (Whitfield)	9

	Horizon.
Cyrtina hamiltonensis Hall	2, 9
Delthyris consobrina (d'Orbigny)	9
Leptæna rhomboidalis (Wilckens)	1, 2, 7, 9
Pholidostrophia iowaensis (Owen)	9
Rhipidomella vanuxemi Hall	2, 10
Spirifer duodenarius (Hall)	1
Spirifer varicosus Hall	1
Spirifer sp.	2, 9
Stropheodonta concava Hall	2, 9
Stropheodonta demissa (Conrad)	2, 9
Stropheodonta hemispherica Hall	1, 9
Stropheodonta parva (?) Hall	9
Stropheodonta perplana (Conrad)	1, 9
Aviculopecten cleon (?) Hall	9
Aviculopecten princeps (Conrad)	9
Conocardium cuneus (?) (Conrad)	9
Glyptodesma erectum (Conrad)	9
Mytilarca sp	9
Paracyclas elliptica Hall	9
Schizodus sp.	9
Pleurotomaria sp.	9
Platyceras bucculentum Hall	9
Platyceras sp.	7
Tentaculites scalariformis Hall	1, 2, 7, 9
Gyroceras sp.	1, 9
Phacops rana Green	10
Phacops sp.	9
Proetus crassimarginatus (?) Hall	1
Proetus rowii (Green)	9
Proetus sp.	2, 9

The section is an extremely interesting one from the fact that it shows so much of the Delaware limestone. The fauna, however, is rather disappointing, because it fails to show many of the distinguishing features which separate it from the Columbus. The Coral layer (No. 10 of the Section) is, however, a most interesting zone since it occurs also in the quarries of the Sandusky region, and thus it affords a means of tying sections together. The specimens of *Cystiphyllum vesiculosum*, which are the most abundant, simply lie on top of the layer of limestone and cover it more or less completely to a depth of two or three inches. Sixteen inches below the Coral zone there is a layer which is frequently filled with *Cyrtina hamiltonensis*.

Bellevue.[1]—This city is in the center of an important group of Devonian outcrops, and in a region where the drift is usually thin. Sinks are not uncommon to the north and west, while to the east rock outcrops even along the roadside. The more important limestone outcrops are west of the city.

[1]See also Swartz, Charles K, *Johns Hopkins Univ. Cir.*, N. S. No. 7, 1907, pp. 60, 61.

The Spence Brothers quarry is located along the Nickel Plate Railroad two miles southwest of Bellevue, and cuts the following section:

		Ft.	In.
12.	Drift and soil	6	0

Columbus limestone.

11.	Hard compact layers of bluish gray limestone, fracturing more or less concoidal	4	0
10.	Compact gray to bluish gray limestone	2	8
9.	Thin bedded uneven layers of very fossiliferous gray limestone. The top layer contains a distinct horizon of *Spirifer acuminatus* associated with *Aviculopecten cleon* (?) as on Kelley's Island	5	0
8.	Comparatively thin bedded gray limestone, very fossiliferous and with a *Spirifer acuminatus* horizon at the top	4	0
7.	Four to ten-inch layers of quite fossiliferous bluish gray limestone	2	10
6.	Layers of a hard gray limestone more or less mottled with white and quite fossiliferous	2	3
5.	A massive layer of fine grained gray limestone	3	3
4.	A massive layer of fine grained gray limestone with some chert in the lower part. (This is probably the "bottom rock" of the Marblehead and Kelley's Island section)	6	4
3.	Layer of gray limestone with no chert	0	10
2.	Light gray chert alternating with layers of grayish brown limestone	2	4
1.	Massive brown limestone with no chert to the bottom of the pit at the crusher	6	6

The following fauna was collected from the upper portion of the quarry:

Diphyphyllum simcoense (Billings)
Favosites hemisphericus (Troost)
Zaphrentis cornicula Edwards and Haime
Atrypa reticularis (Linnæus)
Atrypa spinosa Hall
Camarotœchia tethys (?) (Billings)
Chonetes mucronatus Hall
Cyrtina hamiltonensis Hall
Leptæna rhomboidalis (Wilckens)
Schizophoria propinque Hall
Spirifer acuminatus (Conrad)
Spirifer macrus Hall

9—S. G.—1,000.

Stropheodonta demissa (Conrad)
Stropheodonta hemispherica Hall
Stropheodonta inæquiradiata Hall
Stropheodonta perplana (Conrad)
Aviculopecten cleon (?) Hall
Aviculopecten princeps (Conrad)
Paracyclas elliptica Hall
Platyceras dumosum Conrad
Proetus crassimarginatus Hall

Garrigan's quarry, (now belonging to the Bellevue Stone Co.), one and one-half mile west of Bellevue along the Wheeling and Lake Erie Railroad, has a very similar section, and is cut to about the same depth. It is about a mile north of the Spencer quarry.

The quarry of the Bellevue Stone Company is located just beyond the western edge of the city, and here the following section is well exposed:

	Ft.	In.
7. Soil and drift	2	0

Columbus limestone.

6. Very fossiliferous crystalline gray limestone much weathered and the fossils usually in a poor state of preservation	7	0
5. Gray limestone without chert and fossils rare	3	6
4. Gray to brown limestone with white chert between the layers. The chert is all more or less fossiliferous but that in the lower part is very fossiliferous	6	6
3. Two massive layers of gray to brown limestone with but few fossils	8	6
2. A layer of bluish gray and rather crystalline limestone with few fossils	2	6

Monroe limestone.

1. Massive bluish to drab fine grained banded limestone in layers running from two to three feet in thickness. The top of the upper layer is shaly and has a weathered appearance	17	3

The following fauna was collected in the Devonian portion of this quarry:

	Horizon.
Calcisphæra robusta Williamson	6
Favosites hemisphericus (Troost)	2, 3
Hadrophyllum d'orbignyi (?) Edwards and Haime	4
Syringopora sp.	4

	Horizon.
Zaphrentis cornicula Edwards and Haime	2, 3, 6
Zaphrentis sp.	4
Stromatopora ponderosa Nicholson	2, 3
Cystodictya gilberti (Meek)	4, 6
Fenestella sp.	6
Semicoscinium semi-rotundum (?) (Hall)	4
Athyris vittata indianaensis n. var	4
Atrypa reticularis (Linnæus)	2, 3, 4, 6
Atrypa spinosa Hall	4, 6
Camarotœchia carolina Hall	4
Camarotœchia tetys (Billings)	4
Chonetes mucronatus Hall	4, 6
Cyrtina hamiltonensis Hall	4
Eunella lincklæni Hall	6
Eunella sullivanti Hall	4
Nucleospira concinna Hall	4, 6
Pholidostrophia iowaensis (Owen)	4, 6
Productella spinulicosta Hall	4
Reticularia fimbriata (Conrad)	4
Rhipidomella vanuxemi Hall	4, 6
Schizophoria propinque Hall	4
Spirifer gregarius Clapp	2, 3
Spirifer manni Hall	6
Spirifer varicosus Hall	4
Stropheodonta demissa (Conrad)	4, 6
Stropheodonta hemispherica Hall	2, 3, 4, 6
Stropheodonta inæquiradiata Hall	4
Stropheodonta perplana (Conrad)	6
Conocardium cuneus (Conrad)	4, 6
Ptychopteria (?) sp.	4
Callonema sp.	4
Platyceras carinatum Hall	4
Platyceras dumosum Conrad	4
Platyceras sp.	4

Strong's Ridge is located three miles east of Bellevue. The ridge is made up of the limestone (Prout) member of the Olentangy, at places capped by the Huron shale, and but slightly covered by drift. Over an area of several square miles around this village outcrops of this uppermost member of the Hamilton are quite common. Among these perhaps the best is to be found on the Allen Farr farm on the Bellevue road, three-quarters of a mile northeast of the village of Strong's Ridge and just across the line in Erie county. The following section is just west of the buildings and north of the highway, where a little quarrying has been done.

	Ft.	In.
9. Soil and drift	2	0

Huron Shale.

8. Black bituminous shale	5	0

Olentangy formation.

		Ft.	In.
7.	An outcrop of badly weathered bluish limestone. Formerly this was quarried.....	9	0
6.	Soft blue shale, much weathered.....	2	6
5.	Layer of bluish limestone which is made up almost entirely of Bryozoans.....	0	3
4.	Quite fossiliferous compact blue limestone..	0	6
3.	Bluish shale or shaly limestone.....	2	2
2.	Rather compact fossiliferous blue limestone.	0	4
1.	Fossiliferous weathered blue shale showing in the bottom of the ditch.....	2	0

The following fauna was collected in the weathered material of the soft limestones and shales along the ditch bank just below the pond at this place:

Syringopora perelegans Billings
Cystodictya sp.
Monotrypa sp.
Trematopora sp.
Amboccelia umbonata (Conrad)
Chonetes deflectus Hall
Leiorhynchus kelloggi Hall
Schizophoria striatula (Schlotheim)
Spirifer pennatus (Atwater)
Spirifer sp.
Stropheodonta demissa (Conrad)
Aviculopecten fasciculatus Hall
Modiomorpha subalata (Conrad)
Mytilarca cf. carinata Hall
Pleurotomaria capillaria (?) Conrad
Phacops rana (Green)

This is the most southerly point at which this fauna, in such great abundance, is accessible. Dr. Newberry agreed that it is of Hamilton age, but gave the deposit little consideration beyond that assertion. The fossiliferous limestones and shales of the upper portion of the formation doubtless increase in importance to the north, until at Thedford, Ontario, the whole of the Hamilton is made up of beds similar to those of this section.

Norwalk.—A noted, and perhaps the best, well record of northern Ohio is that known as the "Citizens' well No. 1, Norwalk, Ohio." This well was drilled in 1887 along the banks of the Huron river in Norwalk. The measurements of this section were faithfully recorded by Hon. C. H. Gallup, and the samples preserved by the same gentleman, now form one of the valuable assets of the Firelands Historical Society Museum at Norwalk, Ohio.

The following gives a brief description of the samples of that portion of the section[1] which is of most interest here:

		Feet.
i.	Drift (Samples No. 1-5)	76
h.	Ohio shale (Nos. 6-13). Black and gray shales showing the usual three-fold division	175
g.	Ohio shale and the Prout limestone member of the Olentangy mixed (14). This sample is mostly a black shale with but little limestone	28
f.	Olentangy shale, Prout limestone member, (15). Gray limestone but the sample containing fragments of black shale	5
e.	Olentangy shale (16). Limestone softer and finer than that above and approaching the shaly phase	5
d.	Olentangy shale (17). A soft mud-like sample. Mr. Gallup says that the drill went about four feet every time it was dropped in this portion	59
c.	Olentangy shale (18). Soft blue shale with some pieces of black shale and some chips of blue limestone	13
b.	Delaware and Columbus limestones (19,20). Chipped blue and gray limestones	130
a.	Monroe limestone (21-50). Dolomitic limestone and gypsum	665

The well is twenty-seven hundred and twenty-five feet deep, and is believed to end in the Trenton limestone. The section gives between eighty and one hundred feet as the thickness of the Olentangy, and about one hundred and thirty feet for the combined thickness of the Columbus and Delaware limestones.

Sand Hill.—This village is located at the old Seven-Mile house along the pike south-southwest of Sandusky. A little more than a quarter of a mile west of the village, and a mile southeast of Weyers station on the Pennsylvania Railroad, is the Barnes quarry (see Plate XIV), where the following section is exposed:

		Ft.	In.
11.	Soil and drift	1	0

Delaware limestone.

10.	Bluish gray limestone weathering into thin, rather uneven layers. Few fossils	4	0
9.	Fairly massive blue limestone containing quite a number of Brachiopods, fish teeth, etc.	2	6

[1]Gallup. C. H., *The Firelands Pioneer*, N. S., Vol. XII, 1 900, pp. 522-526

		Ft.	In.
8.	Rather thin bedded blue limestone weathering brown. It contains some white chert and much bituminous matter. The shaly partings contain Crinoid stems and Bryozoans	2	10
7.	White chert	0	4
6.	Brown to blue thin bedded and slightly bituminous limestone with some Crinoid stems but other fossils rare	1	2
5.	Two layers of blue limestone with a few nodules of chert in the lower course	1	4
4.	White chert containing *Leptæna rhomboidalis*	0	4
3.	Blue limestone	2	6
2.	Soft blue Crinoidal limestone with a great quantity of *Leptæna rhomboidalis* bearing white chert in the top	0	10
1.	Two layers of blue limestone completing the section to the bottom of the hole in the southwest part of the quarry	2	2

The fauna here is not rich in species, nor are individuals always plentiful, but the following were picked up and demonstrate its Delaware age.

Fistulipora multiculeata Hall
Camarotœchia sp.
Chonetes coronatus (Conrad)
Cyrtina hamiltonensis Hall
Leptæna rhomboidalis (Wilckens)
Martinia maia (Billings)
Platyceras bucculentum Hall
Platyceras dumosum Conrad
Tentaculites scalariformis Hall

Southward from Sand Hill the Delaware limestone is at the surface, or nearly so, for a mile or two. Mr. Barnes, owner of the quarry, says that on lands now owned by Mr. Parker, a neighbor, a well sunk ninety-six feet with a diamond drill, a few years ago, penetrated ninety feet of blue limestone, and that only the last core of the well was gray. A similar well drilled at Mr. Barnes' own home, penetrated sixty feet of blue limestone and did not pass through it. This is what should be expected, however, since the upper part of the Columbus limestone at Sandusky has a color and texture remarkably similar to that of the Delaware limestone, and the Marblehead sections give only about forty-five feet as the thickness of the gray and brown portions of the Columbus limestone.

Three-quarters of a mile east-southeast from Sand Hill the road crosses Pipe Creek about a quarter of a mile west of Bloomingville. Both above and below the highway bridge at this point there are meager out-

The Delaware limestone in the north wall of the Barnes quarry at Sand Hill near Sandusky. This is probably the upper part of the formation.

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crops of the soft blue shales of the Olentangy. At the barn on the east bank, near the bridge, is an artesian well, which is said to penetrate "fifty feet of soapstone," and to end in the hard blue limestone.

A quarter of a mile east of Bloomingville, a small south branch of Pipe Creek cuts a section in the Prout member of the Olentangy, and also exposes a portion of the shale, north of the ridge road. The following is a section of the rocks at this place:

Olentangy formation.

		Feet.
4.	Blue limestone containing many Crinoid stems, Corals and Bryozoans. *Atrypa reticularis* and *Stropheodonta demissa* are rather common. The limestone has been quarried to some extent	9
3.	Blue shales and limestones, very poorly shown but weathered blocks of it lie on the bank, where such fossils as the following have weathered out: *Syringopora perelegans, Monotrypa sp., Chenetes deflectus, Leiorhynchus kelloggi, Schizophoria striatula, Spirifer pennatus, Stropheodonta demissa, Phacops rana,* etc.	15
2.	Badly weathered marly blue shale	10
1.	Blue shales with disc-like blue limestone concretions. No fossils seen	5

The outcrop of the upper portion of this section is very good, but the shaly banks below are mostly sodded and the section unsatisfactory, except at a few places where the stream strikes the bank at an angle and thus keeps a fresh exposure.

Prout.—This station lies seven miles due south of Sandusky on the Baltimore and Ohio Railroad. The section which Newberry discusses[1] for this locality is about a mile north of the little village, and where the railroad cuts the highest portion of the ridge, or old lake beach. The section now exposed at this point is as follows:

		Ft.	In.
7.	Sand and gravel	14	0
	Huron shale.		
6.	Black shale with a layer of iron pyrites at at the base	2	0
	Olentangy shale, Prout limestone member.		
5.	Dark gray to black chert	0	4
4.	Compact gray limestone, hard and crystalline	1	8

[1]*Geol. Surv. Ohio*, Vol. II, pt. 1, 1874, p. 190.

	Ft.	In.
3. Soft shaly blue limestone with numerous Corals	1	2
2. Mostly soft shaly blue limestone	0	6
1. Compact crystalline bluish gray limestone to the bottom of the ditch	1	4

This gives the total amount of rock exposed in "Deep Cut." Whatever may have been uncovered farther down the ditch to the north is now completely concealed. In the comparatively low flat to the northeast, however, the blue marly shale is said to lie but a few feet below the surface, and has frequently been reached in laying tile. Mr. Smith, who owns the land along the east side of the railroad here, a few years ago dug a well along the northern slope of the ridge. It penetrated five feet of sand and gravel, then entered the blue marly shale.

The fauna of the Prout limestone is not abundant nor is it well preserved, but it carries among its more plentiful species, forms which are common to the Delaware limestone, and this probably accounts for Newberry's erroneous statement that "At Belleville the Huron shale may be seen resting directly upon the Corniferous limestone."[1]

Plum Creek.—Probably the best outcrop of the upper portion of the Olentangy formation is that to be found along Plum Creek (see Plates XV and XVI) a mile and a quarter east of "Deep Cut" and about two miles northeast of Prout station. Here the rocks have a thirteen degree dip to the south, and are covered with but a few feet of drift. The upper part of the following section is exposed on lands owned by E. D. and T. C. Fox and by Mr. Kellar, while the lowest part of the soft blue shale may be seen across the road to the north.

Huron shale.

	Ft.	In.
9. Black bituminous shale	4	0

Olentangy formation.

8. The Prout limestone. Very hard silicious blue limestone with a layer of cherty pyrite at the top. Silicified Corals and Crinoid stems are the most abundant fossils	8	10
7. Covered interval	6	0
6. Layer of fossiliferous soft blue limestone	0	6
5. Fossiliferous soft argillaceous blue shale	3	6
4. Layer of quite hard fossiliferous blue limestone	0	6
3. Fossiliferous soft blue shale	5	0
2. Five inches of limestone overlying four inches of shaly limestone, both fossiliferous, and the latter very fossiliferous	0	9

[1] *Loc. cit.*, p. 190.

Weathered banks of Olentangy shale along Plum Creek near Sandusky. The illustration shows blocks of limestone, similar to those shown in Plate V, weathering out of the soft blue shales. These limestones contain some well preserved fossils.

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	Ft.	In.
1. Soft argillaceous blue shale. This portion contains occasional harder nodules or layers of nodules which approach in appearance the flat limestone concretions of the sections at Delaware. While a few fossils were found in it, probably the great body of this marly shale is as barren as its southern representative.....	15	6

The following is the fauna collected here:

	Horizon.
Favosites sp.	8
Zaphrentis sp.	8
Cystodictya sp.	4
Fenestella sp.	8
Hederella canadensis Nicholson	6
Monotrypa tenuis (?) Hall	6
Trematopora sp.	4, 6
Ambocœlia umbonata (Conrad)	2
Athyris spiriferoides (Eaton)	1
Atrypa reticularis (Linnæus)	8
Chonetes deflectus Hall	2, 3, 4, 5, 6
Chonetes setigerus (?) (Hall)	5
Crania crenistriata Hall	5
Leiorhynchus kelloggi Hall	2, 4, 5, 6
Leiorhynchus laura (?) (Billings)	4, 6
Leiorhynchus sp.	1
Spirifer pennatus (Atwater)	4, 5
Spirifer sp.	8
Stropheodonta demissa (Conrad)	2, 6
Stropheodonta hemispherica Hall	6
Stropheodonta perplana (Conrad)	8
Actinopteria boydi (Conrad)	6
Actinopteria sp.	4
Aviculopecten cleon (?) Hall	6
Cypricardina indenta (?) Conrad	2
Glyptocardia speciosa Hall	2
Grammysia arcuata (Conrad)	2
Grammysia bellatula Hall	2
Grammysia bisulcata (Conrad)	2
Leiopteria rafinesquii Hall	6
Modiomorpha subalata (Conrad)	2
Modiomorpha sp.	6
Nuculites triqueter Conrad	2
Pholidella sp.	2
Pterinea flabellum (Conrad)	6
Schizodus appressus (Conrad)	2
Sphenotus cuneatus (Conrad)	2
Bellerophon lyra Hall	2
Bellerophon sp.	2
Cyrtonella mitella Hall	6
Platyceras erectum (Hall)	4

	Horizon.
Pleurotomaria rotalia Hall	2
Styliola fissurella Hall	5
Orthoceras sp.	2
Barchilina sp.	2
Bollia sp.	2
Bythocypris indianensis (?) Ulrich	3, 5, 6
Bythocypris cf. punctatus Ulrich	2, 6
Phacops rana (Green)	2, 4, 6

At Slate Cut, along the Lake Shore and Michigan Southern Railroad, four miles east-southeast of Sandusky, the Prout member of the Olentangy is nicely exposed with the overlying Huron shale. This is probably the best place to observe the contact between these formations, but the blue shale underlying the limestone is not exposed here.

Wilmer.—The Baltimore and Ohio station called Wilmer is located about four miles south of Sandusky. It is the switch which runs in to the old Casparis quarry. The pit is now nearly filled with water, only eight and one-half feet of Delaware limestone rising above the water, but it is said to have been worked to a depth of twenty-five feet. Six feet below the top of the section here is a layer which is filled with *Cystiphyllum vesiculosum*, and thus recalls the similar layer in the France quarry at Bloomville. From the eight and one-half feet, not covered by water, the following species were collected.

Cystiphyllum vesiculosum Goldfuss
Favosites sp.
Stromatopora ponderosa Nicholson
Cystodictya sp.
Camarotœchia sappho (?) Hall
Chonetes deflectus (?) Hall
Chonetes mucronatus (?) Hall
Chonetes sp.
Eunella lincklæni Hall
Orthothetes pandora (Billings)
Pholidostrophia iowaensis (Owen)
Productella spinulicosta Hall
Spirifer audaculus macronotus Hall
Spirifer macrus (?) Hall
Spirifer sp.
Stropheodonta concava Hall
Stropheodonta demissa (Conrad)
Stropheodonta hemispherica Hall
Stropheodonta perplana (Conrad)
Aviculopecten exactus (?) Hall
Aviculopecten princeps (Conrad)
Aviculopecten sp.
Conocardium cuneus (Conrad)
Paracyclas elliptica Hall
Bellerophon pelops (?) Hall

The Prout limestone member of the Olentangy shale outcropping along Plum Creek. The rocks dip south at an angle of 13° and hence the Huron shale comes in at the fence just above.

(Photo by F. Carney.)

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Platyceras carinatum Hall
Platyceras dumosum (?) Conrad
Pleurotomaria sp.
Gyroceras sp.
Orthoceras eriensis (?) Hall
Orthoceras sp.
Proetus sp.

The lower layers of the quarry are said to be about two feet thick and practically unfossiliferous. This item, together with the layer containing *Cystiphyllum vesiculosum*, serves to tie this outcrop to those next to be discussed, and which stratigraphically extend well towards the top of the formation.

Soldiers' Home.—The State Soldiers and Sailors' Home is located about three-quarters of a mile south of the city limits of Sandusky. The limestone here is practically at the surface, and rock has been taken out at several localities. Two of these are now the sites of active quarrying, and both show a similar section in an impure blue limestone, which, when first broken, has a brown or bluish brown color and a strong petroleum odor. The stone usually has an earthy texture, with films of bituminous matter between beds. There is an occasional band of bluish white chert which contains some Bryozoans, but, in general, chert is extremely rare. These quarries produce a large amount of the beautiful blue building stone for which Sandusky is noted, and in addition, a great quantity of crushed rock.

Just across the road from the south corner of the grounds of the Soldiers' Home, William Hendrickson is operating a quarry with the following section:

	Ft.	In.
6. Drift	2	0
Delaware limestone.		
5. Thin bedded fossiliferous blue limestone	5	6
4. Layers of blue limestone containing many specimens of *Cystiphyllum vesiculosum* associated with *Favosites hemisphericus, Heliophyllum halli,* etc	0	6
3. More or less irregular layers of almost unfossiliferous blue limestone	5	0
2. Two to ten-inch layers of sparingly fossiliferous blue limestone, containing some organic matter Between layers are Crinoidal shale partings with numerous trails	6	3
1. Two massive layers of blue limestone, with some chert between. Sometimes these layers split up into several. The bottom of the quarry is blue limestone	3	6

The following fauna may be found in this quarry:

	Horizon.
Cystiphyllum vesiculosum Goldfuss	4
Diphyphyllum sp.	4
Favosites hemisphericus (Troost)	4
Heliophyllum halli Edwards and Haime	4
Stromatopora sp.	5
Cystodictya gilberti (Meek)	1, 2, 3
Fenestella sp.	1
Monotrypa sp.	3
Atrypa reticularis (Linnæus)	2, 5
Chonetes deflectus Hall	1, 2
Leiorhynchus limitare (Vanuxem)	1, 2
Lingula manni Hall	1
Martinia maia (Billings)	1, 2
Pholidostrophia iowaensis (Owen)	5
Stropheodonta demissa (Conrad)	1, 5
Stropheodonta hemispherica Hall	5
Stropheodonta sp.	5
Conocardium cuneus (Conrad)	5
Cypricardella tenuistriata (Hall)	2
Glyptodesma erectum (Conrad)	1
Nyassa arguta (?) Hall	2
Paracyclas elliptica Hall	2, 5
Platyceras erectum (Hall)	1, 2
Pleurotomaria sp.	5
Tentaculites scalariformis Hall	1

In addition to this small collection of invertebrates, fish teeth are common, while the skulls and jaws of *Onychodus sigmoides* are occasionally found. In the Wagner quarry No. 1, near the east corner of the Soldiers' Home, the Delaware limestone has been opened to a depth of twenty-five feet, and is in every way practically a duplicate of the above section and fauna. In addition to the above species, however, a few other forms were found here. Among these are: *Ambocoelia umbonata, Camarospira eucharis, Chonetes scitulus, Chonostrophia reversa, Stropheodonta concava, Palaeoneilo* (?) *sanduskiensis, Phacops rana,* etc., while traces of the layer containing *Cystiphyllum vesiculosum* can also be found.

Sandusky.—The city of Sandusky is perhaps the most famous Devonian limestone locality in the state, and, taken in connection with the outcrops at Marblehead and on the islands, it well deserves this distinction. In excavating for the basements of residences and other buildings of the city, and in laying water mains and building sewers, it is necessary often to blast away the rock, and such excavations have much the appearance of a newly opened quarry. The city is literally "founded upon a rock."

The vicinity of Hancock street and Sycamore line,[1] in the southeastern part of the city, has long been the scene of the quarrying in-

[1]Prosser, Charles S., *Jour. Geol.*, Vol. XIII, 1905, pp 433, 434.

dustry. At this place a half dozen or so different quarries have been located, but at the present time only two are being operated, and of these the Wagner quarry No. 2 is the larger, and, for the present purpose, the more interesting.

The following is a section of the rocks in the Wagner No. 2, or old Schoepfle quarry.[1]

Delaware limestone.

		Ft.	In.
13.	(This portion is exposed across the street to the south of the quarry and in an old pit now used as a city dump.) Shaly blue to brown limestone with some chert at the base	3	0
12.	Two layers of somewhat massive Crinoidal blue limestone. About three inches of the lower layer is left in spots on the top layer of the Wagner quarry No. 2	2	0

Columbus limestone.

11.	"Bone-bed," poorly defined, but traces of it found on both sides of Hancock street	..	..
10.	Crinoidal blue limestone containing many Corals	3	8
9.	Massive crystalline blue limestone	4	0
8.	Blue limestone showing many Crinoid fragments where weathered	2	6
7.	Several layers of blue limestone containing a great abundance of *Tentaculites scalariformis.* These are more conspicuous in the bedding planes	1	6
6.	Blue limestone separated from the layer below by a prominent iron bearing stylolitic contact	0	6
5.	Massive blue limestone separating into several layers. A *Spirifer acuminatus* horizon occurs three feet above the bottom of this zone	3	8
4.	Very fossiliferous blue limestone bearing a *Spirifer acuminatus* horizon at the top. (One of the wave-marked surfaces, common around Sandusky, is found in the middle of this bed)	1	0
3.	An irregular layer of hard compact bluish gray limestone forming somewhat of a boundary line between the blue and the gray to brown limestone and not distinctly separated from the layer below. (This same layer occurs in the Olemacher quarry at Marblehead)	0	3

[1]See also Swartz, Charles K., *Op. cit.*, p. 58; also Prosser, C. S., *Jour. Geol.*, Vol. XIII, 1905, pp. 436-438.

	Ft.	In.
2. Gray to brown limestone with the fossils more or less in strips or pockets	2	0
1. Very massive grayish brown limestone showing no bedding, but rudely banded. The fossils are in strips or pockets, as in the layer above. The rock has a strong odor of petroleum but where long exposed so that this escapes it, assumes its usual gray color	8	0

The following fossils are among those to be seen in this section:

	Horizon.
Calcisphæra robusta Williamson	1, 2
Cystiphyllum vesiculosum (?) Goldfuss	5, 8, 9, 10
Diphyphyllum sp	2, 4
Favosites emmonsi Rominger	1
Favosites hemisphericus (Troost)	1, 2, 3, 5, 10
Hadrophyllum d'orbignyi Edwards and Haime	12
Stylastrea anna Whitfield	2
Syringopora sp.	5
Zaphrentis cornicula Edwards and Haime	1, 2
Zaphrentis gigantea (?) Rafinesque	1, 4
Zaphrentis sp.	5
Megistocrinus spinulosus Lyon	9
Nucleocrinus verneuili (Troost)	10
Coscinium striatum Hall and Simpson	9
Cystodictya gilberti (Meek)	1, 2, 4, 5, 9
Fenestella sp.	1, 2, 4, 5, 7, 8, 9
Lichenalia sp.	9
Monotrypa sp.	9
Atrypa reticularis (Linnæus)	1, 2, 4, 5, 7, 8, 9
Atrypa spinosa Hall	2, 4, 5, 9
Chonetes mucronatus Hall	1, 7, 8, 9
Cyrtina hamiltonensis Hall	5, 10
Delthyris consobrina (d'Orbigny)	12
Leptæna rhomboidalis (Wilckens)	4, 7, 10, 12
Martinia maia (Billings)	2
Pholidops patina Hall and Clarke	4, 8
Productella spinulicosta Hall	5
Rhipidomella vanuxemi Hall	4, 7, 8, 9, 10, 13
Schizophoria propinque Hall	5, 7
Spirifer acuminatus (Conrad)	4, 5
Spirifer duodenarius (Hall)	10
Spirifer macrus Hall	7, 10
Spirifer varicosus Hall	10
Spirifer sp.	8
Stropheodonta demissa (Conrad)	1, 2, 3, 4, 5, 7, 10
Stropheodonta hemispherica Hall	1, 2, 4, 5, 7, 10
Stropheodonta patersoni Hall	5
Stropheodonta perplana (Conrad)	1, 4, 5, 10
Aviculopecten princeps (Conrad)	10

	Horizon.
Paracyclas elliptica Hall	5, 8, 10
Euomphalus decewi Billings	4
Platyceras dumosum Conrad	9
Platyceras erectum (Hall)	13
Pleurotomaria sp.	4
Tentaculites scalariformis Hall	1, 7, 8
Dalmanites sp.	5
Phacops sp.	5
Proetus sp.	1

This is the section of which the upper part was so long considered to be the equivalent of the section in Campbell's quarry at Delaware, Ohio, and the fauna which led Bownocker to the conclusion that the faunas above and below the "bone-bed" differ less at Sandusky than to the south.[1] Still earlier it formed the basis of Newberry's contention that the "Sandusky limestone," the supposed equivalent of the Delaware limestone, is of Corniferous age, and led him to the erroneous conclusion that the Delaware limestone does not carry a Hamilton fauna. The section is, as we know now, the upper portion of the Columbus limestone and the fauna characteristic of that portion of the formation. In color and texture, however, the rock resembles that of the overlying formation so closely that the deception was a very natural one, especially since the present quarries at the Soldiers' Home had not then been opened, nor were those in the city worked to any considerable depth.[2] Another section which is poorly exposed, but worth mention perhaps, since it duplicates the one just given, is that on Mills Creek in the southwestern part of the city. The section, beginning at the highway arch just south of the Lake Shore and Michigan Southern Railroad tracks, extends along the creek to the south through the O'Donald quarry, up a small westerly branch and into the Wagner Stone Company's quarry No. 4, a little more than a mile south of the city limits.

	Ft.	In.
14. Soil	0	6

Delaware limestone.

13. Weathered blue to brown limestone	2	4
12. Uniform blue limestone having a massive appearance, but breaking up into three to six-inch layers	7	6
11 Even bedded blue limestone in four to six-inch layers with some nodules of chert at the top	2	6
10. Layer of blue limestone containing much white chert	0	3

[1]Bownocker, J. A., *Bull. Sci. Lab. Den. Univ.*, Vol. XI, 1898, p. 31.
[2]*Idem*, p. 29.

	Ft.	In
9. Compact blue limestone in layers about six inches thick	4	0
8. Interval, mostly covered, from near the city limits to the base of the Wagner Stone Company's quarry No. 4	10	0

Columbus limestone.

7. Very fossiliferous hard crystalline blue limestone containing a good many Corals and some fish teeth at the top shown just south of the city limits	3	6
6. Several layers of a massive blue limestone, not very fossiliferous	4	0
5. Rather thin bedded blue limestone, the lower layers containing a great many specimens of *Tentaculites scalariformis*	5	0
4. Quite fossiliferous blue limestone containing a horizon of *Spirifer acuminatus* at the top	3	6
3. Massive gray to bluish gray limestone	2	0
2. Very fossiliferous gray limestone	1	6
1. Fairly massive crystalline gray limestone, quite fossiliferous. This extends to the bottom of the creek at the highway arch	2	0

The O'Donald quarry, which is located in the bed of the creek and within the city limits, is now abandoned, but the Wagner quarry No. 4 is a new plant producing a great quantity of crushed rock, and hence its section is constantly improving.

The following fauna may be found in this section:

	Horizon.
Calcisphæra robusta Williamson	1, 2
Cystiphyllum vesiculosum Goldfuss	7
Favosites hemisphericus (Troost)	1, 5
Stylastrea anna Whitfield	1
Syringopora sp.	4
Zaphrentis cornicula Edwards and Haime	1
Zaphrentis prolifica Billings	4
Zaphrentis sp.	1, 4, 5, 6, 7
Coscinium striatum Hall and Whitfield	4
Cystodictya gilberti (Meek)	2
Cystodictya sp.	10, 12
Fenestella sp.	2, 3, 4, 5, 7, 12
Orthonota sp.	7
Atrypa reticularis (Linnæus)	3, 4, 5, 6, 7
Atrypa spinosa Hall	4
Camarotœchia sp.	6
Chonetes deflectus Hall	9, 10, 11, 12
Chonetes mucronatus Hall	3, 4

near the truth. It is certain at least that there has been a very material thickening of this deposit in northern Ohio.

SECTIONS AND FAUNAS OF THE NORTHWESTERN DISTRICT

In the crescent shaped area of Devonian in the northwestern part of the state, the relief of the land is low and drainage seldom cuts through the drift covering to bed rock. The geological structure of this corner is therefore but imperfectly known. However, some good sections of Devonian have been uncovered by artificial means during the past few years, and thus an opportunity to add a little to the knowledge of these important formations has been afforded.

As already pointed out, there are but two Middle Devonian formations represented in this part of the State, the Columbus limestone and the Traverse formation. The Michigan term, Traverse, is introduced here because the rocks referred to it are but the southward extension of the same formation that occurs in that state, and because the rocks carrying a Hamilton fauna in northwestern Ohio cannot well be referred to either of the central and northern Ohio formations which carry a fauna of that age. The Traverse formation is the approximate equivalent of the Delaware limestone and Olentangy shale of the Columbus and Sandusky regions.

The Columbus limestone consists of the usual fossiliferous gray limestone, which passes downward into a sparingly fossiliferous brown limestone resembling the lower part of the same formation in central Ohio. The total thickness of this formation probably does not exceed sixty feet. The Traverse formation consists mainly of limestone, but it also includes some beds of shale and shaly limestone. The limestone of the basal portion of the Traverse is lithologically identical with that of the upper part of the Columbus limestone, the transition being marked only by the introduction of vast numbers of Hamilton species. At the top, however, the Ohio shale rests directly upon a limestone as at Sandusky and hence a decided break occurs.

Silica.[1]—Eight miles west of Toledo and two and a quarter miles southwest of Sylvania is the small quarrying village known as Silica. At this place, which is only a few miles south of the Michigan-Ohio line, the quarries at present being worked are in the Sylvania sandstone and Lucas limestone. Several old quarries in the Devonian, however, are located across the road to the north and west of those of the Toledo Stone and Glass Sand Company, and among these is the old abandoned Lee quarry which furnishes the following section:

[1]Gilbert, G. K., *Geol. Surv., Ohio*, Vol. I, 1873, pp. 575-577.
Also Prosser, C. S., *Jour. Geol.*, Vol. XI, 1903, pp. 540, 541.

the other hand none of these horizons have been located north of Marion: in the quarry of the Bellevue Stone Company at Bellevue, where the lower portion of the Columbus limestone and the upper part of the Monroe limestone are well exposed, a true *Spirifer gregarius* zone does not occur, nor has it been located in any other quarry between the Sandusky region and Marion; the rather sparingly fossiliferous lower portion of the Columbus limestone, other than the lowest zone, in the Sandusky region bears a striking structural and lithological similarity to the lower almost barren part of the same formation in central Ohio; and finally the interval between the *Spirifer gregarius* beds and the top of the formation at Marblehead and Kelley's Island is double that of the interval in question at Columbus. This leads to the alternative view that perhaps there has been a diminution in the thickness of the formation as a whole and that the fauna occurring in the base of the formation of the Sandusky region reappears later in the vicinity of Columbus. A probable real loss of the lower massive portion of the formation takes place between the Columbus and Bellefontaine regions.

The Norwalk well gave one hundred thirty feet as the thickness of the Devonian limestones. Substracting the sixty-one feet of Columbus limestone obtained as above, there are sixty-nine feet left as the thickness of the Delaware limestone. The diamond drill core, reported by Mr. Barnes of Sand Hill, showed ninety feet of blue limestone. The Wagner quarry No. 2 gives seventeen feet as the thickness of the blue portion of the Columbus limestone. Substracting this from the ninety feet of the diamond drill core at Sand Hill, it gives seventy-three feet as the thickness of the Delaware limestone. This seems an incredible thickness for that formation, but indications have been that a rapid thickening of the Hamilton formations takes place in northern Ohio, and, since the two methods tally within four feet, perhaps seventy feet may not be too much to assign to this formation. The use of the Sand Hill well section can be valuable only in case the entire formation is still intact, and this is essentially the case.

There are no outcrops, north of those in Franklin and Delaware counties, which give the entire thickness of the Delaware limestone. It seems more than probable, however, that the Barnes quarry represents the upper part of the formation, the Hendrickson quarry the middle and above, while the lowermost layers are known to occur in the Hancock street and Sycamore line quarries at Sandusky, as also in the Lake Shore Railroad quarry south of Venice. There is thus the possibility of a considerable amount of Delaware limestone occurring in the intervals between the sections mentioned.

The thickness of the Olentangy formation in northern Ohio is not definitely known. The Norwalk well gave about eighty feet of marly shales and limestones assigned to this formation, and that is probably

east shore of Point Pelee Island is a Devonian rock identical with the Columbus limestone and the same rock has been quarried to a depth of thirty feet near the club house at the northwest point of the island. The common fossils of the Columbus limestone are also the conspicuous ones here.

THICKNESS OF THE MIDDLE DEVONIAN AT SANDUSKY.

In linking together the sections at Sandusky, Marblehead and Kelley's Island in order to determine the thickness of the Columbus limestone, rather startling results are obtained. The equivalence of bed No. 3 in the Wagner quarry No. 2, Sandusky, and bed No. 8 in the Olemacher quarry, Marblehead, was established on its lithological appearance and upon the character, both lithological and faunal, of the beds lying immediately above and below it. The lithology of the layer at the two places is striking enough in itself to make one suspect the equivalence, and the identity of the faunas above and below it makes the case reasonably sure. The identity of "bottom rock" at the Marblehead and Kelley's Island quarries is too evident to need discussion. Using then the South Side quarry, Kelley's Island, the Olemacher quarry, Marblehead, and the Wagner quarry No. 2, Sandusky, the total thickness of the Columbus limestone may be obtained as follows:

Columbus limestone.

	Ft.	In.
c. "Bone-bed" to the base of bed No. 3 of the Wagner quarry No. 2, Sandusky	17	0
b. Base of bed No. 8 (the equivalent of bed No. 3 in Wagner No. 2) to the top of "bottom rock" in the Olemacher quarry, Marblehead	13	6
a. Top of "bottom rock" to the Silurian-Devonian contact in the South Side quarry, Kelley's Island	30	6
Total	61	0

This is a decrease of forty-four feet from the total thickness at Columbus. The basal portion of the formation in the Sandusky region carries an abundance of specimens of *Spirifer gregarius,* and perhaps, as Swartz suggests in his diagrams,[1] this is the *Spirifer gregarius* zone of central Ohio and that the diminution in thickness has taken place entirely below that horizon. In support of this view is the absence at Marblehead and Kelley's Island, of the *Spirifer macrothyris* zone, the Gastropod fauna of the chert zone, the Corals of the Coral zone, etc., all of which fall below the *Spirifer gregarius* zone in central Ohio. On

[1]*Op. cit.*, p. 63.

Monroe limestone.

		Ft.	In.
2.	Compact gray to brown limestone containing a Silurian fauna	9	6
1.	Hard layer of very compact banded blue or dark gray limestone to the bottom of the quarry. (See the Johnson's Island section)	1	0

The following fauna was collected from No. 3 of the above section:

Calcisphæra robusta Williamson
Diphyphyllum simcoense (Billings)
Favosites hemisphericus (Troost)
Stylastrea anna Whitfield
Syringopora tabulata Nicholson
Zaphrentis cornicula Edwards and Haime
Stromatopora ponderosa Nicholson
Fenestella sp.
Atrypa reticularis (Linnæus)
Atrypa spinosa Hall
Chonetes mucronatus Hall
Cyrtina hamiltonensis Hall
Eunella lincklæni Hall
Leptæna rhomboidalis (Wilckens)
Nucleospira concinna Hall
Reticularia fimbriata (Conrad)
Rhipidomella vanuxemi Hall
Spirifer divaricatus Hall
Spirifer gregarius Clapp
Spirifer macrus Hall
Stropheodonta demissa (Conrad)
Stropheodonta hemispherica Hall
Stropheodonta inæquiradiata Hall
Conocardium cuneus (Conrad)
Paracyclas elliptica Hall
Bellerophon sp.
Loxonema sp.
Palæotrochus kearneyi (Hall)
Platyceras dumosum Conrad
Pleurotomaria sp.
Turbo shumardi Verneuil
Coronura diurus (Green)
Phacops cristata Hall
Proetus crassimarginatus Hall

This gives a fairly good idea of the richness of this basal fauna in northern Ohio. As at the neighboring quarries, the lithological change from the Silurian to the Devonian is not great, but the faunal break is very marked and the contact certain.

The Canadian islands lying to the north of Kelley's Island have sections very similar to those just discussed. The greater portion of the

	Horizon.
Fenestella sp.	10
Monotrypa tenuis (Hall)	9
Athyris vittata indianaensis n. var	10
Atrypa reticularis (Linnæus)	9, 10
Camarotœchia billingsi Hall	10
Camarotœchia tethys (Billings)	10
Camarotœchia sp.	10
Chonetes arcuatus Hall	10
Chonetes hemisphericus Hall	10
Chonetes mucronatus Hall	9, 10
Cyrtina hamiltonensis Hall	10
Leptæna rhomboidalis (Wilckens)	10
Orthothetes pandora (Billings)	10
Pholidops patina Hall and Clarke	10
Productella spinulicosta Hall	10
Rhipodomella vanuxemi Hall	10
Schizophoria propinque Hall	9, 10
Spirifer acuminatus (Conrad)	10
Spirifer gregarius Clapp	10
Spirifer grieri Hall	10
Spirifer varicosus Hall	10
Stropheodonta concava Hall	10
Stropheodonta demissa (Conrad)	9, 10
Stropheodonta hemispherica Hall	7, 9, 10
Stropheodonta perplana (Conrad)	9, 10
Actinopteria sp.	10
Aviculopecten cleon (?) Hall	10
Aviculopecten princeps (Conrad)	10
Conocardium cuneus (Conrad)	10
Modiomorpha concentrica (Conrad)	10
Paracyclas elliptica Hall	10
Sanguinolites (?) sanduskiensis Meek	10
Callonema lichas Hall	10
Euomphalus decewi Billings	10
Loxonema sp.	10
Platyceras carinatum Hall	10
Pleurotomaria lucina (?) Hall	10
Tentaculites scalariformis Hall	9, 10
Coronura diurus (Green)	10
Phacops cristata Hall	9

A short distance to the west of this, at the north lake shore, is another small quarry which was formerly operated in connection with the main part of the North Side quarry. Here the following section is exposed:

Columbus limestone.

	Ft.	In.
3. Massive grayish or light brown limestone, rather porous and containing an abundant fauna, especially in the lower part. The fossils occur generally as molds and casts	14	0

	Horizon.
Coronura diurus (Green)	10
Phacops cristata Hall	11
Proetus sp.	8, 10

The *Spirifer acuminatus* horizons mentioned in the section last given and elsewhere, are conspicuous and fairly well marked, but this fossil is not limited to these horizons. A careful examination of the intervening beds has been rewarded with a few specimens at a number of different localities. Whether it is safe to correlate these horizons here with those of distant sections is rather doubtful.

In the North Side quarry the following section is exposed:

Columbus limestone.

		Ft.	In.
10.	Thin bedded fossiliferous gray limestone, the top layer containing *Spirifer acuminatus* in great numbers	10	8
9.	Very fossiliferous gray limestone somewhat more massive than the layers above	7	6
8.	"Bottom rock." A massive layer of gray to brown limestone. It sometimes shows one or two minor bedding planes but is usually one layer	7	8
7.	Brown limestone with rather soft gray to white chert intermixed	3	9
6.	Brown limestone with no chert	1	0
5.	Thin grayish brown shaly parting	0	3
4.	Massive brown limestone with some chert in three discontinuous layers	4	3
3.	Massive brown limestone somewhat banded and in one or two beds. Its fauna is not so abundant as in the upper part of the section	14	6
2.	Very fossiliferous brown to grayish brown limestone	4	0

Monroe limestone.

1.	Brown limestone carrying a Silurian fauna	1	0

The following fauna was collected in the upper part of the section at this locality:

	Horizon.
Calcisphæra robusta Williamson	9, 10
Diphyphyllum strictum (Edwards and Haime)	9
Diphyphyllum sp.	8, 10
Favosites hemisphericus (Troost)	8, 9, 10
Favosites pleurodictyoides Nicholson	9, 10
Favosites sp.	10
Zaphrentis cornicula Edwards and Haime	8, 9, 10
Stromatopora ponderosa Nicholson	8, 9
Cystodictya gilberti (Meek)	9, 10

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The massive portion of the Columbus limestone lying below "bottom rock" in the South Side quarry, Kelley's Island.
(Photo by C. R. Stauffer.)

	Ft.	In.
8. "Bottom rock." Gray to grayish brown limestone usually occurring as one massive layer, but at some places splitting into several or a number of layers. Very fossiliferous with Corals especially conspicuous at the top	8	6
7. Fossiliferous gray limestone with some chalky white chert in the upper part. This layer forms the base of the north part of the quarry	1	9
6. Soft gray shale. (This shale is the equivalent of that forming the bottom of the Olemacher quarry)	0	4
5. Layer of gray limestone with very little or no chert	0	10
4 Hard cherty gray limestone	2	3
3. Covered interval	12	0
2. Massive gray limestone containing an abundant fauna. This rock is exposed along the lake just east of the United States Life Saving Station	5	6

Monroe limestone.

1. Fossiliferous compact drab limestone to lake level	2	0

The following fauna was collected from this section:

	Horizon.
Calcisphæra robusta Williamson	2, 7, 10, 11
Cyathophyllum rugosum Hall	11
Diphyphyllum verneuilanum (Edwards and Haime)	11
Diphyphyllum sp.	11
Favosites hemisphericus (Troost)	2, 8, 9, 10, 11
Syringopora tabulata Edwards and Haime	11
Zaphrentis cornicula Edwards and Haime	2, 7, 10, 11
Zaphrentis sp.	2, 4, 8, 9
Stromatopora ponderosa Nicholson	11
Stromatopora sp	2
Cystodictya gilberti (Meek)	10, 11
Cystodictya sp.	10
Fenestella sp.	2
Monotrypa tenuis (Hall)	2, 11
Atrypa reticularis (Linnæus)	2, 8, 9, 10, 11
Chonetus mucronatus Hall	2, 5, 10, 11
Chonetus sp.	2, 8
Cyrtina hamiltonensis Hall	2
Delthyris raricosta Conrad	2
Leptæna rhomboidalis (Wilckens)	2
Nucleospira concinna Hall	2, 10, 11
Orthothetes pandora (Billings)	10

	Horizon.
Rhipidomella vanuxemi Hall	2, 8, 9, 11
Schizophoria propinque Hall	10, 11
Spirifer acuminatus (Conrad)	11
Spirifer divaricatus Hall	2
Spirifer gregarius Clapp	2
Spirifer manni Hall	10, 11
Spirifer varicosus Hall	11
Spirifer sp.	2, 10, 11
Stropheodonta concava Hall	10, 11
Stropheodonta demissa (Conrad)	2, 9, 10, 11
Stropheodonta hemispherica Hall	2, 5, 8, 9, 10, 11
Stropheodonta inæquiradiata Hall	2, 11
Stropheodonta perplana (Conrad)	2, 7, 10, 11
Actinopteria boydi (Conrad)	10
Conocardium cuneus (Conrad)	2, 11
Modiomorpha concentrica (Conrad)	11
Paracyclas elliptica Hall	10, 11
Bellerophon pelops Hall	11
Callonema lichas (Hall)	11
Euomphalus decewi Billings	11
Loxonema robustum Hall	11
Loxonema sp.	11
Palæotrochus kearneyi (Hall)	2
Platyceras carinatum Hall	10, 11
Platystoma sp.	10
Trochonema meekanum Miller	10
Tentaculites scalariformis Hall	10
Gyroceras sp.	11
Orthoceras sp.	10
Phacops cristata Hall	2
Phacops sp.	10

Kelley's Island.—This famous island lies five miles off Marblehead and twelve miles north of Sandusky. Its quarries have long been known to science because of the remarkable grooves which are so nicely shown in the glaciated surface of the Columbus limestone. Lime, heavy building stone and crushed rock are produced here on a large scale; the latter, however, is beginning to assume the greater importance. In the South Side quarry the following section is shown: (See Plates XVIII and XIX).

	Ft.	In.
14. Soil and drift	2	0

Columbus limestone.

13. Thin bedded bluish gray limestone	1	6
12. Thin bedded bluish gray limestone with *Spirifer acuminatus* occurring occasionally at the top	3	0
11. Thin bedded bluish gray limestone with a well developed *Spirifer acuminatus* horizon at the top	5	6

The thin bedded upper portion of the Columbus limestone in the west side of the South Side quarry, Kelley's Island. The massive rock just back of the stone cars is "bottom rock."

(Photo by C. R. Stauffer.)

	Ft.	In.
10. Rather thin bedded very fossiliferous gray limestone. *Favosites hemisphericus* especially conspicuous. A horizon of *Spirifer acuminatus* at the top	5	0
9. Very fossiliferous gray limestone in three to five-inch layers. A *Spirifer acuminatus* horizon at the top	7	10
8. "Bottom Rock." A massive layer of grayish brown limestone, but where much weathered it splits up into thinner beds	9	0
7. Grayish brown limestone with much gray to white chert intermixed	3	6
6. Compact brown limestone with no chert	1	0
5. Parting of gray to light brown shale. (This is the same shaly band that forms the bottom of the Olemacher section)	0	3
4. Massive brown limestone. The surface under the shale is rather uneven and is marked with vermicular trails	4	0
3. Massive gray to grayish brown limestone with few or no distinct bedding planes. Fossils not abundant	12	8
2. A very fossiliferous crystalline gray limestone	4	0

Monroe limestone.

1. Massive compact dark brown banded limestone carrying a Silurian fauna	2	6

The physical break between the Monroe and the Columbus limestones is not great, although the rock texture is somewhat different in the two. Blocks a foot thick may be collected, in the top of which is a rich Devonian fauna, while in the bottom the Silurian fauna is almost equally abundant. The faunal break is thus sharp and decided, and the possibility of mistaking the contact remote, although the two formations, notwithstanding the unconformity, are completely welded together.

The following fauna was collected in this quarry.

	Horizon.
Calcisphæra robusta Williamson	8, 9
Cystiphyllum sulcatum (?) Billings	7
Cystiphyllum sp.	7
Diphyphyllum bellis (?) Davis	2
Diphyphyllum stramineum Billings	2
Diphyphyllum strictum (Edwards and Haime)	8
Diphyphyllum sp.	7, 8, 9
Favosites emmonsi Rominger	2
Favosites hemisphericus (Troost)	2, 7, 8, 9
Favosites pleurodictyoides Nicholson	8, 9
Pleurodictyum problematicum Goldfuss	9
Syringopora tabulata Edwards and Haime	2, 10
Zaphrentis cornicula Edwards and Haime	2, 7, 8, 9

	Horizon.
Zaphrentis gigantea Rafinesque	9
Zaphrentis sp.	8, 11
Stromatopora ponderosa Nicholson	2
Stromatopora sp.	8
Syringostroma columnaris Nicholson	10
Syringostroma densa Nicholson	2
Dolatocrinus sp.	2
Coscinium striatum Hall and Simpson	9
Cystodictya gilberti (Meek)	7, 8, 9, 10
Fenestella sp.	2, 8, 9
Monotrypa tenuis Hall	2, 9
Athyris vittata indianaensis n. var	9, 12
Atrypa reticularis (Linnæus)	2, 8, 9, 10
Camarotœchia tethys (Billings)	8, 10
Chonetes hemisphericus Hall	10
Chonetes mucronatus Hall	2, 7, 8, 9
Chonetes sp.	7, 8, 9, 10, 11
Crania crenistriata Hall	9
Cyrtina hamiltonensis Hall	10, 11
Eunella lincklæni Hall	2, 7
Leptæna rhomboidalis (Wilckens)	8, 9, 10
Orthothetes pandora Billings	8, 9, 10
Productella spinulicosta Hall	8, 10
Pholidops patina Hall and Clarke	9, 10
Rhipidomella vanuxemi Hall	2, 5, 6, 7
Schizophoria propinque Hall	2, 9, 10
Spirifer acuminatus (Conrad)	9, 10, 11, 12
Spirifer gregarius Clapp	2, 9
Spirifer fornacula (?) Hall	10
Spirifer macrus Hall	10
Spirifer sp.	8, 12
Stropheodonta concava Hall	8
Stropheodonta demissa (Conrad)	7, 8, 9, 10
Stropheodonta hemispherica Hall	2, 7, 8, 9, 10
Stropheodonta inæquiradiata (?) Hall	8
Stropheodonta perplana (Conrad)	2, 8, 9
Strophonella ampla Hall	2
Actinopteria sp.	10
Aviculopecten cleon (?) Hall	10
Aviculopecten princeps (Conrad)	10
Aviculopecten sp.	9
Conocardium cuneus (Conrad)	2, 10
Paracyclas elliptica Hall	2, 7, 12
Bellerophon pelops (?) Hall	2, 10
Callonema lichas (?) (Hall)	7
Callonema sp.	10
Loxonema sp.	10
Palæotrochus kearneyi (Hall)	2
Platyceras carinatum (?) Hall	10
Platyceras dumosum Conrad	12
Pleurotomaria sp.	7
Gyroceras cyclops Hall	10
Chasmops calypso (?) Hall	10

	Horizon.
Zaphrentis cornicula Edwards and Haime	4, 6
Stromatopora ponderosa Nicholson	4
Cystodictya gilberti (Meek)	4, 5, 6, 7, 8
Fenestella sp.	6, 7, 8
Monotrypa tenuis (Hall)	4, 7
Athyris vittata indianaensis n. var	7
Atrypa reticularis (Linnæus)	4, 6, 7, 8, 9
Atrypa spinosa Hall	9
Camarotœchia carolina Hall	9
Camarotœchia tethys (Billings)	8, 9
Chonetes mucronatus Hall	4, 5, 6, 7, 8
Cyrtina hamiltonensis Hall	9
Eunella lincklæni Hall	6
Pentamerella arata (Conrad)	9
Pholidops patina Hall and Clarke	5, 7
Rhipidomella vanuxemi Hall	9
Schizophoria propinque Hall	4, 8
Spirifer acuminatus (Conrad)	9
Spirifer varicosus Hall	7, 8
Spirifer sp.	4, 5, 9
Stropheodonta demissa (Conrad)	4, 5, 6, 7, 9
Stropheodonta hemispherica Hall	4, 5, 6, 7, 9
Stropheodonta perplana (Conrad)	6, 7, 9
Conocardium cuneus (Conrad)	6
Nucula sp.	8
Paracyclas elliptica Hall	9
Callonema lichas (Hall)	9
Euomphalus decewi Billings	6
Loxonema sp.	7
Tentaculites scalariformis Hall	5
Phacops sp.	5, 7, 9
Proetus sp.	9

The James quarry, which is one of the larger and likewise of the older quarries, is located just south of the railroad station at Marblehead. Its section, which is essentially that of all the other nearby quarries, together with that of the rocks at the lake shore just below, is as follows:

Columbus limestone.

		Ft.	In.
12.	Fossiliferous gray limestone to the top of the quarry on the west side near the cemetery and ball grounds	3	0
11.	Fossiliferous gray limestone with *Spirifer acuminatus* occurring in great numbers at the top	10	6
10.	A granular light gray limestone which is especially full of *Calcisphæra robusta*	1	0
8.	Thin bedded fossiliferous gray limestones. Layers irregular and about two or three inches thick	5	6

Marblehead.[1]—The quarries at Marblehead, near the east end of the peninsula north of Sandusky Bay, are the largest of the quarries in the Devonian limestone within the state. In each of several quarries many acres have been worked to a depth of twenty or thirty feet. Lime is still being burned here, but the production of crushed rock has grown rapidly and is now by far the more important industry.

The Olemacher quarry is located at the south side and near the east end of the peninsula. While its lime-kilns and crusher are now abandoned, its section is still fresh and most interesting, since it forms a connecting link between the Kelley's Island quarries and those in Sandusky. The following is a section of the rocks here.

Columbus limestone.

	Ft.	In.
9. Rather thin bedded bluish gray limestone, containing *Spirifer acuminatus* near the base	3	8
8. Irregular layer of hard compact bluish gray limestone, not always separated from the layer below. (This is the equivalent of No. 3 in the section of the Wagner quarry No. 2)	0	3
7. Usually thin bedded gray or slightly bluish limestone, quite fossiliferous. The fossils are in streaks or pockets and the rock is not always clearly separated from that below	2	0
6. Massive gray limestone rudely banded and very fossiliferous, the fossils occurring in streaks and pockets	4	8
5. Brown to grayish brown limestone, quite fossiliferous	6	10
4. Massive brown to grayish brown rock which is known to the quarrymen as "bottom rock," probably because it was formerly the last course that was taken out	7	6
3. Layers of white chalky chert nodules	0	3
2. Brown limestone with no chert and few fossils	1	6
1. Soft gray shale in the bottom of the quarry	0	4

The following is the fauna collected at this point:

	Horizon.
Calcisphæra robusta Williamson	5, 6, 7
Cystiphyllum vesiculosum Goldfuss	4
Favosites hemisphericus (Troost)	4, 5, 6, 9
Pleurodictyum problematicum Goldfuss	6
Stylastrea anna Whitfield	5, 6, 7

[1]See also Swartz, Charles K., *Op. cit.*, p. 57.

	Ft.	In.
6. A massive layer of gray or brownish gray limestone sparingly fossiliferous	5	0
5. A massive layer of grayish brown limestone, very fossiliferous and with an uneven contact with the underlying formation. *Spirifer gregarius* is an abundant fossil	2	4

Monroe limestone.

4. Rather thick layer of banded brown limestone	4	9
3. A layer made up almost entirely of *Stromatopora* sp. and a few Corals. The rock has a dark bluish or purplish brown color	0	9
2. Hard layers of gray limestone conspicuously banded	0	9
1. Grayish brown banded limestone in massive layers to the bottom of the quarry. Near the middle it contains *Meristella* sp	6	6

The following are only a few of the species abundant in the fauna:

	Horizon.
Calcisphæra robusta Williamson	10
Diphyphyllum verneuilanum (Edwards and Haime)	8
Favosites hemisphericus (Troost)	5, 8
Favosites limitaris (?) Rominger	5
Zaphrentis cornicula Edwards and Haime	8
Stromatopora ponderosa Nicholson	8
Cystodictya gilberti (Meek)	5, 8
Fenestella sp.	5
Monotrypa tenuis (Hall)	5
Polypora robusta (Hall)	8
Atrypa reticularis (Linnæus)	5, 8
Chonetes mucronatus Hall	8
Crania crenistriata Hall	5
Cryptonella lens Hall	8
Pholidostrophia iowaensis (Owen)	5
Rhipodomella vanuxemi Hall	5
Spirifer gregarius Clapp	5, 8
Spirifer sp.	8
Stropheodonta demissa (Conrad)	5, 8
Stropheodonta hemispherica Hall	5, 8
Strophonella ampla Hall	5
Conocardium cuneus (Conrad)	5, 8
Platyceras erectum (Hall)	10
Pleurotomaria lucina Hall	5
Phacops cristata Hall	5, 8

Cystiphyllum vesiculosum (?) Goldfuss	Columbus ls.
Diphyphyllum verneuilanum (Edwards and Haime)	"
Favosites hemisphericus (Troost)	"
Zaphrentis cornicula Edwards and Haime	"
Zaphrentis sp.	"
Stromatopora ponderosa Nicholson	"
Nucleocrinus verneuili (Troost)	"
Cystodictya gilberti (Meek)	"
Fenestella sp.	"
Stictopora sp.	"
Atrypa reticularis (Linnæus)	"
Camarotœchia tethys (Billings)	"
Chonetes mucronatus Hall	"
Chonetes sp.	"
Cyrtina crassa Hall	"
Eunella sp.	"
Leptæna rhomboidalis (Wilckens)	"
Pentamerella arata (Conrad)	"
Pholidostrophia iowaensis (Owen)	"
Productella spinulicosta Hall	"
Rhipdomella venuxemi Hall	"
Spirifer acuminatus (Conrad)	"
Spirifer duodenarius (Hall)	"
Spirifer manni Hall	"
Stropheodonta demissa (Conrad)	"
Stropheodonta hemispherica Hall	"
Stropheodonta perplana (Conrad)	"
Paracyclas elliptica Hall	"
Euomphalus decewi Billings	"
Platyceras carinatum Hall	"
Platyceras rictum Hall	"
Tentaculites scalariformis Hall	"
Proetus crassimarginatus Hall	"
Proetus welleri n. sp	"

Johnson's Island.—This island lies in Sandusky Bay, about three miles north of the city of Sandusky and about two miles west of Cedar Point. On the southeast side of the island quarrying has been quite extensive, and together with the cliff three hundred feet to the north has uncovered the following section:

Columbus limestone.

	Ft.	In.
10. Massive gray limestone shown in the cliff at the east end of the old fortification. Among the abundant fauna is *Calcisphæra robusta* and *Spirifer gregarius*	16	0
9. Covered interval	10	8
8. Thin bedded gray or brownish gray limestone quite fossiliferous	5	0
7. A massive layer of grayish brown limestone	1	6

The contact between the Columbus and Delaware limestones in the Lake Shore Railroad quarry south of Venice. The "bone-bed" is shown at the point where the hammer and collecting bag are placed.

(PHOTO BY C. S. PROSSER.)

Railroad quarry. (See Plate XVII). Here the "bone-bed" is fairly well shown, and the dividing line between the Columbus and Delaware limestones is evident.[1] The following section was measured in this quarry:

	Ft.	In.
8. Soil and drift	1	0
Delaware limestone.		
7. Blue limestone alternating with layers of gray chert	2	6
6. Massive and thin bedded crystalline blue limestone. Weathered surface very Crinoidal	3	4
5. Rather impure blue limestone with a tendency to be shaly	2	0
Columbus limestone.		
4. "Bone-bed," not always well defined	..	..
3. A rather thin bedded compact blue limestone	2	4
2. A layer made up largely of *Diphyphyllum verneuilanum*	0	4
1. More or less crystalline to gray limestone and very fossiliferous	7	10

This quarry is at the summit of a low anticline, the axis of which passes north and south just west of the middle of the pit. The similarity of the section to the same horizon at Columbus is most striking, and this is brought out more clearly by the following fauna:

Hadrophyllum d'orbignyi Edwards and Haime	Delaware ls.
Cystodictya sp.	"
Camarotœchia prolifica Hall	"
Camarotœchia tethys (Billings)	"
Chonetes deflectus (?) Hall	"
Chonetes scitulus Hall	"
Delthyris consobrina (d'Orbignyi)	"
Leptæna rhomboidalis (Wilckens)	"
Leiorhynchus limitare (?) (Vanuxem)	"
Orbiculoidea minuta (Hall)	"
Orthothetes pandora (Billings)	"
Stropheodonta demissa (Conrad)	"
Glyptodesma erectum (Conrad)	"
Grammysia bisulcata (Conrad)	"
Bellerophon sp.	"
Platyceras erectum (Hall)	"
Platyceras sp.	"
Tentaculites scalariformis Hall	"

[1]See Prosser, Charles S., *Jour. Geol.*, Vol. XIII, 1905, pp. 434-436, and half-tone on p. 440, which is shown in Plate XVII.

	Horizon.
Chonetes sp.	3, 4, 5, 7
Chonostrophia reversa (Whitfield)	10
Eunella sp.	7
Leptæna rhomboidalis (Wilckens)	4, 5, 7, 9, 10, 11, 12, 13
Martinia maia (Billings)	12
Orthothetes pandora (Billings)	3
Pentamerella arata (Conrad)	6, 7
Pholidops patina Hall and Clarke	2
Reticularia fimbriata (Conrad)	7
Rhipidomella vanuxemi Hall	3, 4, 6, 7
Spirifer acuminatus (Conrad)	4
Spirifer duodenarius (Hall)	7
Spirifer macrus Hall	3
Spirifer manni Hall	4
Spirifer sp.	2, 3, 4, 5, 6
Stropheodonta demissa (Conrad)	1, 2, 3, 4, 5, 6, 7
Stropheodonta hemispherica Hall	1, 4, 5, 6, 7
Stropheodonta perplana (Conrad)	1, 2, 4, 5, 6
Aviculopecten princeps (Conrad)	5, 12
Aviculopecten sp.	5
Glyptodesma erectum (Conrad)	10, 12
Paracyclas elliptica Hall	4, 5, 7, 12
Dentalium sp.	7
Euomphalus decewi Billings	7
Platyceras carinatum Hall	7
Platyceras dumosum Conrad	4
Platyceras erectum (Hall)	10
Tentaculites scalariformis Hall	1, 3, 4, 5
Gyroceras sp.	4
Phacops sp.	6, 9, 10
Proetus rowii Green	7
Proetus sp	2, 7, 12

Aside from the similarity of the Columbus limestone portion of this section and its fauna to that just given for the Wagner quarry No. 2, the lowest zone is in rock which is very similar in its fauna and lithological appearance to the top layers of the James quarry at Marblehead. Whether the horizon of the Sandusky and Marblehead localities is identical cannot be certainly established, since the fauna depended upon is that of a considerable portion of the Columbus limestone at Marblehead. The error in considering the localities as reaching the same horizon is not a serious one, however, and probably does not exceed a few feet. A more exact means of correlating the sections of Columbus limestone of this vicinity will be pointed out later.

Venice.—This is the first station west of Sandusky along the Lake Shore and Michigan Southern Railroad. The section in question for this locality lies a mile and three-quarters south of Venice, and about two and one-half miles southwest of the main portion of Sandusky. It is at the end of the Venice switch and has usually been called the Lake Shore

Columbus limestone.

	Ft.	In.
3. Thin bedded Crinoidal gray limestone containing many Corals	2	0
2. Massive porous brown limestone with few fossils	9	0
1. Massive brown limestone containing some poorly preserved fossils and some fossiliferous white chert	2	6

The following species were collected here:

Favosites hemisphericus (Troost)
Stromatopora ponderosa Nicholson
Cystodictya gilberti (Meek)
Atrypa reticularis (Linnæus)
Cyrtina hamiltonensis Hall
Nucleospira concinna Hall
Pholidostrophia iowaensis (Owen)
Productella spinulicosta Hall
Rhipidomella vanuxemi Hall
Spirifer acuminatus (Conrad)
Spirifer gregarius Clapp
Spirifer segmentum Hall
Stropheodonta demissa (Conrad)
Stropheodonta hemispherica Hall
Strophonella ampla Hall
Aviculopecten sp.
Conocardium cuneus (Conrad)
Paracyclas elliptica Hall
Pterinea flabellum (Conrad)
Callonema lichas (?) Hall
Pleurotomaria lucina Hall
Trochonema meekanum Miller
Orthoceras sp.
Phacops cristata Hall

The most interesting section of this locality, however, is that along Ten Mile Creek,[1] just south of the quarries, where the following section may be found.

Traverse formation.

	Ft.	In.
14. Massive bluish drab limestone containing iron pyrites, traces of petroleum and a few fossils	10	0
13. Thin unevenly bedded blue limestone with several layers of white chert, both fossiliferous	3	0

[1]*Ohio Nat.*, Vol. VIII, 1908, pp. 271-276.

	Ft.	In.
12. Blue shale and soft shaly blue limestone containing much iron pyrites and quite fossiliferous	2	6
11. Bluish gray limestone alternating with layers of fossiliferous white chert	3	6
10. A rather compact drab limestone with many fossils, occurring as casts, and much fossiliferous white chert	2	0
9. Bluish gray shaly limestone with irregular layers of fossiliferous white chert. At places much of this zone becomes a mass of Corals	2	0
8. Blue limestones interbedded with soft blue shaly layers	4	0
7. Covered interval, at least in part consisting of blue shale as shown by material dredged from the bottom of the creek. It includes the contact of the Columbus and Traverse formations	20	0
Columbus limestone.		
6. Very fossiliferous crystalline gray limestone	13	0
5. Compact brown limestone in massive beds and containing a few fossils in the upper part	42	0
Lucas limestone.		
4. Compact drab limestone showing a banded structure. These layers are quite massive but weather into much thinner layers. Several fossiliferous horizons occur near the middle of the zone	63	0
3. Compact drab limestone with some dark gray to brown sandy layers. This zone is probably the basal portion of the Lucas limestone rather than a part of the underlying formation	36	0
Sylvania sandstone.		
2. A fine grained friable white sand becoming coarser and of a conglomeratic nature in the lower part. The extreme base is made up of limestone pebbles imbedded in the sandstone	43	0
Tymochtee formation.		
1. Thin bedded compact drab limestone exposed at the bottom of the sandstone quarry at Silica, but better along the creek to the east and south	20	0

The following fauna occurs in the rocks along this creek:

	Horizon.[1]
Cladopora canadensis Rominger	8, 9
Cladopora sp.	8, 9
Cyathophyllum rugosum Hall	6
Cystiphyllum vesiculosum Goldfuss	9
Diphyphyllum panicum (Winchell)	9
Favosites arbusculus Hall	9
Favosites hamiltoniæ Hall	9
Favosites hemisphericus (Troost)	6, 9
Favosites nitellus Winchell	8, 9
Favosites placentus Rominger	9
Favosites radiciformis Rominger	9
Favosites sp.	14
Heliophyllum halli Edwards and Haime	9
Streptelasma ungula Hall	8, 9
Strombodes alpinensis Rominger	9
Syringopora sp.	8, 9
Zaphrentis cornicula Edwards and Haime	6
Zaphrentis simplex Hall	8, 9
Stromatopora granulata Nicholson	9
Stromatopora ponderosa Nicholson	6
Dolatocrinus canadensis (?) Whiteaves	14
Dolatocrinus sp.	14
Gennæocrinus (?) sp.	14
Hexacrinus leai (?) (Lyon)	8, 9
Megistocrinus spinulosus Lyon	6, 14
Cystodictya gilberti (Meek)	6
Dendropora elegantula Billings	8, 9
Fenestella arkonensis Whiteaves	8, 9
Fenestella emaciata (?) Hall	8, 9
Fenestella sp.	9, 10, 11
Fenestrapora biperforata (?) Hall	8, 9
Fistulipora sp	8
Lichenalia sp.	8
Orthopora bipinulata (?) (Hall)	8, 9
Reteporina rombifera (Hall)	8, 9
Reteporina striata (?) (Hall)	8, 9
Stictoporina plumea (Hall and Schuchert)	8, 9
Streblotrypa hamiltonensis Nicholson	8, 9
Ambocœlia umbonata (Conrad)	7, 8, 9
Atrypa reticularis (Linnæus)	6, 8, 14
Atrypa spinosa Hall	6, 14
Camarotœchia horsfordi Hall	14
Centronella ovata Hall	9, 10, 11
Chonetes arcuatus (?) Hall	6
Chonetes coronatus (Conrad)	8, 9
Chonetes deflectus Hall	8, 9

[1]Note—The species assigned to horizons 7, 8, 9, 10 and 11 were collected, for the most part, on the banks of the creek among the loose material thrown out in deepening the channel. As many as a half dozen trips have been made to this section, and it is believed that the assignment is fairly correct.

	Horizon.
Chonetes hemisphericus Hall	5
Chonetes lepidus Hall	8, 9
Chonetes mucronatus (?) Hall	8, 9
Chonetus scitulus Hall	8, 9
Chonetes vicinus (Castelnau)	8, 9
Crania crenistriata Hall	8, 9
Cryptonella planirostris Hall	10
Cyrtina hamiltonensis Hall	6, 8, 9
Dalmanella lepida (?) Hall	8, 9
Eunella lincklæni Hall	8, 9
Gypidula sp.	9, 10, 11
Leiorhynchus kelloggi Hall	8, 9
Leiorhynchus laura (Billings)	8, 9
Lingula ligea Hall	14
Nucleospira concinna Hall	6, 8, 9
Orthothetes sp.	8, 9
Pholidostrophia iowaensis (Owen)	6, 8, 9
Productella spinulicosta Hall	6
Rhipidomella penelope (?) Hall	8, 9
Rhipidomella vanuxemi Hall	6, 8, 9
Schizophoria striatula (Schlotheim)	8, 9
Spirifer acuminatus (Conrad)	6
Spirifer audaculus (Conrad)	8, 9, 10, 11
Spirifer gregarius Clapp	6
Spirifer macrus Hall	8, 9, 11
Spirifer manni Hall	6
Spirifer pennatus (Atwater)	8, 9
Spirifer varicosus Hall	6
Spirifer venustus Hall	8
Spirifer sp.	14
Stropheodonta concava Hall	9, 14
Stropheodonta demissa (Conrad)	6, 8, 9, 14
Stropheodonta hemispherica Hall	6, 8, 9
Stropheodonta perplana (Conrad)	6, 9, 10, 11, 14
Strophonella ampla Hall	6
Tropidoleptus carinatus (?) Conrad	8, 9
Actinopteria boydi Hall	9, 10, 11
Actinopteria decussata Hall	8, 9
Aviculopecten sp.	6, 8
Conocardium cuneus (Conrad)	6
Leiopteria dekayi (?) Hall	8, 9
Limopteria macroptera (Conrad)	8, 9
Limopteria pauperata Hall	6
Paracyclas elliptica Hall	6
Pterinea flabellum (Conrad)	6, 8
Bellerophon cf. pelops Hall	14
Callonema cf. bellatulum (Hall)	11
Callonema lichas (?) (Hall)	6
Loxonema hamiltoniæ Hall	11
Loxonema sp.	14
Pleurotomaria lucina Hall	6
Pleurotomaria sulcomarginata (Conrad)	11

	Horizon.
Pleurotomaria sp.	9, 10, 11, 14
Trochonema meekanum Miller	6
Coleolus tenuicinctus (?) Hall	8, 9
Tentaculites bellulus Hall	8, 9
Tentaculites scalariformis Hall	6
Gomphoceras pingue (?) Hall	14
Goniatites (?) sp.	14
Orthoceras arkonense Whiteaves	14
Orthoceras cf. eriense Hall	14
Orthoceras sp.	6
Phacops cristata Hall	6
Phacops rana (Green)	8, 9
Proetus macrocephalus Hall	8, 9

This Traverse fauna differs markedly from that of the Hamilton formations east of the anticlinal axis. Even the fossiliferous upper layers near Sandusky carry but a small per cent. of the species found in the Hamilton of this section.

Whitehouse.—About twelve miles south of Silica and sixteen miles southwest of Toledo on the Wabash Railroad, the Columbus limestone is being quarried at the village of Whitehouse. The two quarries in the southeastern edge of the village, formerly the Ryan and Pray, are now operated by the Whitehouse Stone Company, and the following section is uncovered. (See Plate XX.)

	Ft.	In.
11. Soil and drift	2	0
Traverse formation.		
10. Rather compact crystalline gray limestone containing a great many Corals, especially *Acervularia davidsoni* and *Favosites hemisphericus*	0	6
9. Compact finely crystalline gray limestone very full of *Chonetes coronatus* associated with *Tropidolpetus carinatus*	0	10
8. Gray to bluish gray limestone, compact and crystalline. It contains an occasional specimen of *Chonetes coronatus* and *Cyrtina umbonata alpinensis*	2	0
7. Compact blue to brown limestone markedly less fossiliferous than the other layers	1	6
6. Very fossiliferous blue to gray limestone containing a great abundance of specimens of *Cyrtina umbonata alpinensis*	1	0
Columbus limestone.		
5. Thin uneven bedded bluish gray limestone containing an abundant fauna	9	3

	Ft.	In.
4. Bluish gray limestone, in three to six-inch layers, containing a variety of fossils, but especially full of *Tentaculites scalariformis*	1	10
3. Light bluish gray limestone in six to fourteen-inch layers. Fossils comparatively few	3	8
2. Massive bluish gray limestone containing pockets of fossiliferous white chert	3	0
1 Massive bluish brown crystalline limestone weathering blue. It contains a good many fossils, but they are generally not well preserved	2	0

There is no distinct line separating the Columbus from the Traverse here. Lithologically and physically the section is continuous, but the introduction of a great abundance of the Hamilton species, *Cyrtina umbonata alpinensis*, is taken as an indication of the certainly changed fauna which is exhibited in the layers a few feet higher in the section.

The following fauna was collected in this quarry:

	Horizon.
Calcisphæra robusta Williamson	5, 6
Acervularia davinsoni Edwards and Haime	9, 10
Cladopora tela Davis	5
Cladopora sp.	10
Cyathophyllum sp.	10
Cystiphyllum vesiculosum Goldfuss	9
Favosites emmonsi Rominger	5
Favosites hemisphericus (Troost)	10
Favosites nitellus Winchell	10
Favosites sp.	5, 10
Syringopora sp.	10
Zaphrentis cornicula Edwards and Haime	5
Zaphrentis gigantea (?) Rafinesque	5
Stromatopora nodulata Nicholson	9, 10
Stromatopora ponderosa Nicholson	5, 10
Syringostroma densa Nicholson	5
Cystodictya gilberti (Meek)	5
Fenestella sp.	5, 6
Monotrypa tenuis (Hall)	10
Amphigenia elongata (Vanuxem)	5
Athyris vittata (?) Hall	8
Atrypa reticularis (Linnæus)	4, 5, 6, 7, 8, 10
Atrypa spinosa Hall	5
Camarotœchia billingsi Hall	5
Chonetes coronatus Conrad	8, 9
Chonetes mucronatus Hall	5, 8
Chonetes sp.	7
Cryptonella lens Hall	5
Cyrtina hamiltonensis Hall	2
Cyrtina umbonata alpinensis Hall	6, 8, 9

The west wall of the East quarry at Whitehouse. The greater part of this section is Columbus limestone, but a few feet at the top belong to the Traverse.

(Photo by C. S. Prosser.)

	Horizon.
Eunella lincklæni Hall	5
Orthothetes pandora (Billings)	5
Pentamerella arata (Conrad)	5
Pentamerella sp	8
Pholidops patina Hall and Clarke	5
Pholidostrophia iowaensis (Owen)	3, 4, 5
Productella spinulicosta Hall	5, 6
Rhipidomella vanuxemi Hall	5
Schizophoria propinque Hall	5
Spirifer acuminatus (Conrad)	4, 5
Spirifer audaculus (Conrad)	6, 8, 9, 10
Spirifer gregarius Clapp	5
Spirifer grieri (?) (Hall)	5
Spirifer lucasensis n. sp	7, 8
Spirifer manni Hall	5
Spirifer sp.	5, 6
Stropheodonta demissa (Conrad)	5, 6
Stropheodonta hemispherica Hall	4, 5, 6, 8, 9
Stropheodonta inæquiradiata Hall	3, 4, 5
Stropheodonta perplana (Conrad)	9
Tropidoleptus carinatus (Conrad)	9
Aviculopecten sp.	5, 10
Conocardium cuneus (Conrad)	4, 5, 6, 9
Glyptodesma erectum (Conrad)	9, 10
Glyptodesma occidentale Hall	5
Paracyclas elliptica Hall	5, 7, 8
Pterinea flabellum (Conrad)	5, 9
Callonema lichas Hall	5
Loxonema robustum (?) Hall	5
Murchisonia desiderata Hall	5
Murchisonia cf. maia Hall	6
Platyceras carinatum Hall	8
Platyceras dumosum Conrad	5
Platyceras sp.	9
Pleurotomaria arata Hall	5
Pleurotomaria lucina Hall	5
Pleurotomaria sp.	5
Coleolus crenatocinctus Hall	5
Tentaculites scalariformis Hall	2, 3, 4, 5, 6, 7
Gyroceras sp.	5
Orthoceras sp.	5
Dalmanities sp.	8
Phacops cristata Hall	5
Proetus crassimarginatus Hall	5
Proetus planimarginatus Meek	5
Proetus sp	5
Dipterus eastmani n. sp	5

Grand Rapids.[1]—This town is on the south bank of the Maumee River at the point where it is crossed by the Toledo, St. Louis and West-

[1]Winchell, N. H., *Geol. Surv. Ohio*, Vol. II, 1874, p. 379. His "Oriskany sandstone" at Otsego Ford (*ibid*, pp. 380, 381), is the Sylvania sandstone.

ern Railroad, ten miles south-southwest of Whitehouse and about twenty-five miles southwest of Toledo. At the west end of Main street there is a small quarry exposing six and one-half feet of massive fine grained brown limestone with few fossils. The bottom of the quarry was filled with water, but at the railroad bridge north of town the base of the Columbus limestone is shown resting with a conspicuous uneven bituminous contact upon the Lucas limestone. The lower part of the Devonian appears to be slightly arenaceous here.

Among the abundance of fragmentary fossils, the following were well enough preserved to be identified; Crinoid fragments, *Pholidostrophia iowaensis*, *Spirifer* sp., *Stropheodonta hemispherica*, *Loxonema* sp. *Coleolus crenatocinctus*, *Phacops cristata*, etc.

Junction.—This is a small inland village located in Paulding county at the junction of the East-west and North-south canals, about nine miles southwest of Defiance. The point of interest lies along the Auglaize River, which flows a half mile east of the canal. The last of the Ohio shale may be seen in the bed of this river, about three miles above Defiance. From this point to Charloe, a distance of nearly twelve miles, the river flows on limestone the greater part of the way. The quarries mentioned in the earlier reports[1] are mostly in the bed of Auglaize River, and have never been worked to any considerable depth because of the difficulty in draining them. Just south of the last outcrop of Ohio shale is the Town Newton property, where some rock was taken out and a crusher installed a few years ago. The foot or so of rock shown above the river level here is a rather massive hard fossiliferous bluish gray limestone. A quantity of bluish white chert and cherty limestone, which has been taken from the bottom of this pit and now lies around the old crusher, adds to the similarity of this rock to the upper part of the section along Ten Mile Creek, to which horizon it probably belongs.

The most important section in this region is that of the A. V. Hager quarry, just below the bridge over the Auglaize River, one-half mile east of Junction, where the following measurements were made.

	Ft.	In.
6. Till and boulder clay	20	0
Traverse formation.		
5. Fossiliferous blue limestone with much white chert	1	4
4. Rather pure blue limestone. This is the portion that was formerly burned for lime	2	8

[1]Winchell, N. H., *Op. cit.*, pp. 339-341, 427.

	Ft.	In.
3. Massive layers of compact bluish limestone. There is a thin but conspicuous layer of iron pyrites at the top	7	0
2. Massive layers of impure blue limestone with shaly partings	5	0
1. Very fossiliferous soft blue shale or shaly limestone extending to the bottom of the lowest portion of the quarry	2	0

The following fauna was collected from this section.

	Horizon.
Aulopora serpens Goldfuss	1
Cyathophyllum sp.	3
Heliophyllum halli Edwards and Haime	4, 5
Cystodictya gilberti (Meek)	1, 4
Cystodictya incisurata (Hall)	1
Fenestella sp.	4
Monotrypa sp.	1
Trematoporella sp.	1, 4
Athyris spiriferoides (Eaton)	2
Atrypa reticularis (Linnæus)	2, 3
Chonetes coronatus Conrad	1
Chonetes deflectus Hall	1
Chonetes lepidus Hall	1
Chonetes scitulus Hall	1, 4
Chonetes sp.	2
Crania crenistriata Hall	4
Cyrtina hamiltonensis Hall	1, 2, 4
Rhipidomella cyclas Hall	4
Rhipidomella vanuxemi Hall	1, 2, 4
Schizophoria striatula (Schlotheim)	1, 4
Spirifer pennatus (Atwater)	1
Spirifer sp.	2, 4
Stropheodonta demissa (Conrad)	2, 4
Stropheodonta hemispherica Hall	2, 4
Stropheodonta perplana (Conrad)	1, 4
Glyptodesma erectum (Conrad)	1
Pterinea flabellum (Conrad)	1, 2, 4
Platyceras erectum (Hall)	4
Platyceras sp.	1, 5
Tentaculites scalariformis Hall	1, 4
Orthoceras nuntium Hall	5
Bythocypris indianensis (?) Ulrich	1
Bythocypris cf. punctatus Ulrich	1
Phacops rana (Green)	1, 4
Phacops sp.	2

In the shale at the bottom of the section there are concretionary masses of limestone which are filled with Bryozoans and other fossils. In general the shales and shaly partings of the section are much more fossiliferous than the limestones.

From a half to three-quarters of a mile up stream from the bridge at Hager's quarry, a considerable amount of limestone was formerly taken from the bed of a small run entering the Auglaize River from the west. The rock at this locality is doubtless lower stratigraphically than that of the Hager quarry, and is a massive blue limestone with shale partings of the same color. The following fauna was collected here:

Aulopora serpens Goldfuss
Cladopora frondosa Nicholson
Heliophyllum halli Edwards and Haime
Romingera unbellifera (Billings)
Trachypora elegantula Billings
Zaphrentis sp.
Fenestella arkonensis Whiteaves
Athyris vittata Hall
Atrypa reticularis (Linnæus)
Cyrtina umbonata alpinensis Hall
Cyrtina sp.
Rhipidomella vanuxemi Hall
Schizophoria striatula (Schlotheim)
Spirifer audaculus (Conrad)
Spirifer pennatus (Atwater)
Stropheodonta concava Hall
Stropheodonta demissa (Conrad)
Pterinea flabellum (Conrad)
Tentaculites bellulus Hall

Scott's Ford.—About two miles up stream from the Hager quarry and just above the mouth of Flat Rock Creek the road crosses the river without a bridge at a place known as Scott's Ford. The stream is here flowing on limestone which, like that further north, dips to the northwest. The section at this place is as follows:

Traverse formation.

	Ft.	In.
5. Blue limestone with some shaly partings...	3	0
4. Bluish gray limestone with numerous specimens of *Acervularia davidsoni* and *Favosites hemisphericus*. This is the equivalent of the top layer (No. 10 of section) in the Whitehouse quarry.....	0	6
3. Bluish gray limestone containing *Chonetes coronatus*	1	0
2. Bluish gray limestone with an abundant fauna	4	0

Columbus limestone.

1. Very fossiliferous bluish gray limestone....	1	0

The following is only a small portion of the rich fauna that may be found here:

	Horizon.
Acervularia davidsoni Edwards and Haime	4
Aulopora serpens Goldfuss	2
Cyathophyllum sp.	2, 4
Favosites hemisphericus (Troost)	3, 4
Zaphrentis sp.	1, 3, 4
Cystodictya gilberti (Meek)	1
Athyris vittata Hall	2
Atrypa reticularis (Linnæus)	1, 2, 3, 4, 5
Camarotœchia sp.	2
Chonetes coronatus Conrad	3
Chonetes sp.	1
Cyrtina hamiltonensis Hall	1, 2
Cyrtina umbonata alpinensis (?) Hall	4, 5
Delthyris consobrina (d'Orbigny)	4, 5
Nucleospira concinna Hall	1
Pholidops patina Hall and Clarke	1
Pholidostrophia iowaensis (Owen)	1
Productella spinulicosta Hall	1, 2
Spirifer audaculus (Conrad)	3, 4
Spirifer gregarius (?) Clapp	1
Spirifer pennatus (Atwater)	5
Spirifer sp.	1
Stropheodonta concava Hall	5
Stropheodonta demissa (Conrad)	1, 2, 3, 5
Stropheodonta hemispherica Hall	1, 2
Actinopteria boydi (Conrad)	1
Modiomorpha concentrica (Conrad)	1
Schizodus sp.	1
Platyceras sp.	1
Orthoceras constrictum (?) (Vanuxem)	5
Phacops rana (Green)	5

There can be no doubt but Nos. 3 and 4 of this section are the equivalents of Nos. 9 and 10 of the Whitehouse section. The latter section, therefore, lies mostly below, while the Hager quarry lies entirely above the Scott's Ford section.

Antwerp.—Since the abandonment of the old iron furnace at Antwerp, Paulding county, there has been no limestone taken from the bed of the Maumee River and there is little to be seen at the old quarry, as it is below water level much of the time. The few blocks now available carry a Columbus fauna, and it is more than probable that the entire mass of rock belongs to that formation.

THE THICKNESS AND COMPOSITION OF THE MIDDLE DEVONIAN IN NORTHWESTERN OHIO.

It is impossible to determine the exact thickness of the Middle Devonian formations in the northwestern part of the state, since no

single outcrop gives the entire section and the well records are unsatisfactory.[1] The Ten Mile Creek section, however, is thought to be essentially complete; it certainly gives at least a close approximation to the whole. This makes the total thickness about one hundred twelve feet, of which a little more than half is probably Traverse.

The Columbus limestone, although much reduced in thickness as compared with the central Ohio section, duplicates the formation as it appears east of the anticline. The Traverse formation, or the time equivalent of the Delaware limestone and the Olentangy shale, has changed materially. Faunally it is more decidedly Hamilton than either of the latter, except possibly the Olentangy formation just below the Prout limestone member at Sandusky. While lithologically the resemblance is perhaps more remote, there is still some similarity here. In northwestern Ohio, where the thickness of the Hamilton has greatly diminished and the amount of shale in comparison to the limestone has become insignificant, and at Sandusky, where the reverse is true, the Hamilton consists of limestone at top and bottom with a shale between. This same arrangement holds for Ontario, where the Hamilton has a thickness of more than two hundred feet,[2] but here with limestones intercalated in the shaly middle portion. An interesting, and perhaps significant, feature of this Ontario Hamilton is that it also "passes into the Corniferous limestone" as the Traverse does at Whitehouse and Scott's Ford.

CONCLUSION.

From the foregoing record of sections and faunas, it seems to be a safe deduction that the Middle Devonian in Ohio is confined to the Onondaga and Hamilton phases; that these two divisions are as distinct as those of the same age in any other region; and that the history of these formations in this state has been an integral part of that of the adjacent territory. Hence the following correlation of these formations[3] with New York divisions has been assumed:

		Ohio		New York
Middle Devonian	Traverse	Olentangy formation	.....	Hamilton Beds
		Delaware limestone		Marcellus shale
	Columbus limestone		.....	Onondaga limestone

[1]*Geol. Surv. Ohio*, Vol. VI, 1888, pp. 243-254.
[2]Gibson, Thomas W., 12th Rept. *Ont. Bur. Mines*, 1903, p. 42.
[3]See *Jour. Geol.*, Vol. XV, 1907, p. 596.

CHAPTER III.

THE RELATIONSHIPS OF THE MIDDLE DEVONIAN FAUNAS OF OHIO.

INTRODUCTION.

The animal life of any geological period may be separated into a number of more or less distinct faunas which are intimately related to the conditions under which they existed. Among marine faunas, such as those under consideration, the more important factors influencing life are: the temperature of the sea, its salinity and depth; the presence of land barriers between portions of the same or different basins; the existence of favorable or unfavorable currents; the amount and kind of detritus which is being brought down by running water; the kind and abundance of food to be obtained; the presence or absence of hostile or rival faunas, etc.

Perhaps no other single condition, which has influenced the distribution of fossil faunas, has received so much consideration as has that of the ancient land barriers and continents—the paleogeography of the earth. The former existence of land connections between continents now separated is accepted by all geologists, and to the vertebrate paleontologist a demonstrated fact, since it is an obvious impossibility for land animals, which must have arisen from the same ancestors, to spread over widely separated land areas unless there existed some means of easy communication between them. The effect of such a barrier on marine faunas is of course absolutely prohibitive to migration in that direction. Other conditions, however, must at times be equally unfavorable to migration. Thus a fossiliferous bed of limited extent may be found within a formation of almost barren strata. This is well illustrated by the colony of Crinoids in the Olentangy shale at Delaware, Ohio. Here within the barren shales is a lens of limestone, 5 inches thick and traceable along the cliff for a distance of 13½ feet, which is made up almost entirely of the fragments of Crinoids. No other such bed is known anywhere within the formation.

But the matter of the distribution of life is still more complicated by the fact that a barrier for one species may not check another at all, or, if so, only temporarily. Thus a fauna is often found to change gradually by the elimination of those species unsuitable to the new con-

ditions and the addition of others better adapted to the changed conditions, until finally the association of species is so different that it is indeed a different fauna.

GENERAL DISTRIBUTION.

The difficulty of properly delimiting ancient faunal provinces lies chiefly in the inability to obtain a full collection of species from some of the most critical localities and, as yet, insufficient knowledge of other localities where such collections might be obtained. However, certain more or less well defined areas in various parts of the earth are known to have formed portions of the Devonian epicontinental seas. Among these may be mentioned: southern Australia and a portion of New Zealand, South Africa, the region north of Lake Tchad in the Sahara, a portion of Asia Minor and Persia, north central Siberia, central and southern China, portions of Japan, the northern and southern provinces of Europe, a considerable portion of South America, and the various provinces of North America. These districts all bear certain broad faunal relations to one another, as might be expected in distant portions of the sea of any period. Thus certain species of Corals and Brachiopods are found in Europe, Asia, Australia and South America which are considered identical with the North American species. So close is the relation between the Devonian faunas of Europe and certain faunal provinces of North America, and again between North and South America, that there can be no doubt but that conditions developed which favored migration between these portions of the ancient Devonian sea.

DISTRIBUTION IN NORTH AMERICA.

In North America the Devonian outcrops are usually grouped together in four general areas.[1] These are:

The Eastern Border Area, including Gaspé, New Brunswick, and northern New England.

The Eastern Continental Area, best known in New York, Ontario, Michigan, Ohio, Indiana, southern Illinois, Kentucky and less perfectly southward to the Gulf states.

The Interior Continental Area developed in west central Illinois, Missouri, Iowa and thence northwestward through Manitoba and along the valley of the Mackenzie River.

The Western Continental Area in the Great Basin region, including portions of Nevada, California and adjacent territory.

In addition to these a fifth, the Western Border Area, might be made to include the Devonian rocks of the islands off the southeastern coast of Alaska.[2]

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[1]Williams. H. S., *Am. Jour. Sci.*, 3rd Ser., Vol. XXXV, 1888, pp. 51-59.
[2]Kindle, E. M., *Jour. Geol.*, Vol. XV, 1907, pp. 314-337.

These provinces have had more or less of an independent history, but at times there must have been an intimate connection between certain of them, since a fauna which normally occurs in one is found lapping over into another basin and there mingled with the species indigenous to that territory in strata above those containing the usual fauna of that province. The history of the incursions of these provincial faunas[1] into the interior basin of the Eastern Continental Area comprises one of the most interesting events in the development of North American faunas.

THE EASTERN CONTINENTAL SEA.

By the close of the Silurian, the ancient epicontinental sea which covered the greater part of the present Mississippi basin, had withdrawn from a large part of the interior, and the territory now occupied by Ohio and adjoining states to the west and north, together with a large tract beyond, was dry land. This withdrawal probably took place to the north, to the south, and to a less extent to the east, with the Cincinnati arch bowing up into a complete barrier between these various portions of the sea. With the beginning of the Devonian a readvance of the sea set in, but Ohio was not affected until the Middle Devonian when a considerable portion of its territory was again invaded. The pebbles of this old shore line are still to be found in the basal conglomerate of the Columbus region. Thus the Devonian begins in Ohio with a marked unconformity, below which the rocks vary in age from Niagaran to Cayugan, and above it from Onondaga to Hamilton.

OUTCROPS IN OHIO.

On account of its peculiar outline, the Eastern Interior sea was naturally divided into several basins, of which those bordering the Cincinnati land mass may be referred to as, the Ohio basin to the east, the Michigan basin to the north, and the Indiana basin to the west. (See Plates XXII and XXIII.) The outcrops of Middle Devonian within the state follow the borders of the Michigan and Ohio basins, so that there is a crescent shaped area in the northwest and to the east a strip crossing the central part of the state from north to south, with an outlier at Bellefontaine. The history of these two areas, separated by a ridge of Silurian limestones, has been somewhat different both in sedimentation and in life development.

THE CENTRAL DISTRICT.

The central strip is made up of three formations of this age, the Columbus limestone, the Delaware limestone, and the Olentangy shale,

[1]Weller, Stuart, *Jour. Geol.*, Vol. X, 1902, pp. 423-432; Schuchert, Charles, *Am. Geol.*, Vol. XXXII, 1903, pp. 137-162.

all of which are very distinct divisions in the vicinity of Columbus. Within each of these three formations there are several zones containing faunal associations quite distinct in themselves. Among these latter may be mentioned the Coral zone, the Eversole chert or Gastropod zone, the *Spirifer gregarius* zone of the Columbus limestone, and the "Marcellus" zone of the Delaware limestone. These are all of much interest and have received their proportional consideration. It is with the broader general relations, however, that the present discussion is concerned and only incidentally with these zones as they may throw some light on the migratory movements of the whole fauna.

The following table gives the fauna obtained from the formations of this area of outcrops:

FAUNA OF THE MIDDLE DEVONIAN OF THE CENTRAL DISTRICT.

INVERTEBRATA.

	Columbus.	Delaware.	Olentangy.
RHIZOPODA			
Calcisphæra robusta Williamson	x	..	..
SPONGIAE			
*Receptaculites devonicus Whitfield	x	..	..
ANTHOZOA			
Aulacophyllum convergens Hall	x	..	..
Aulacophyllum sulcatum (d'Orbigny)	x	..	..
Aulopora serpens Goldfuss	..	x	..
Bothrophyllum cinctutum Davis	x	..	..
Chonophyllum magnificum (?) Billings	x	..	..
Cladopora frondosa Nicholson	x	..	..
Cladopora pulchra Rominger	x	..	..
Cladopora robusta Rominger	x	..	..
Cladopora tela (?) Davis	x	..	..
Cyathophyllum multigematum (?) Davis	x	..	..
Cyathophyllum rugosum Edwards and Haime	x	..	..
Cyathophyllum validum Hall	x	..	..
Cystiphyllum ohioense Nicholson	x	..	..
Cystiphyllum sulcatum (?) Billings	x	..	..
Cystiphyllum vesiculosum Goldfuss	x	x	..
Cystiphyllum sp.	x	..	..
Diphyphyllum archiaci Billings	x	x	..
Diphyphyllum bellis (?) Davis	x	..	..

*Not collected by the writer.

	Columbus.	Delaware.	Clentangy.
Diphyphyllum simcoense (Billings)	x	..	..
Diphyphyllum stramineum Billings	x	..	..
Diphyphyllum strictum (Edwards and Haime)	x	..	..
Diphyphyllum verneuilanum (Edwards and Haime	x	..	..
Diphyphyllum sp.	x	x	..
*Favosites basalticus Goldfuss	x	..	..
Favosites emmonsi Rominger	x	?	..
Favosites goldfussi d'Orbigny	x	..	..
Favosites hemisphericus (Troost)	x	x	..
Favosites limitaris (?) Rominger	x	..	..
Favosites maximus (Troost)	x	..	..
Favosites pleurodictyoides Nicholson	x	..	..
Favosites radiciformis Rominger	x	..	..
Favosites sp.	x	x	..
Hadrophyllum d'orbignyi Edwards and Haime	x	x	..
Heliophyllum halli Edwards and Haime	x	x	..
Heliophyllum porcilatum Hall	x	..	..
Heliophyllum sp.	..	x	..
*Michelinia convexa d'Orbigny	x	..	..
Pleurodictyum problematicum Goldfuss	x	..	..
Stylastrea anna Whitfield	x	..	..
Syringopora perelegans Billings	..	..	x
Syringopora tabulata Edwards and Haime	x	..	..
Syringopora sp.	x	..	..
Zaphrentis cornicula Edwards and Haime	x	..	..
*Zaphrentis edwardsi Nicholson	x	..	..
Zaphrentis gigantea Rafinesque	x	..	..
Zaphrentis prolifica Billings	x	..	..
Zaphrentis spissa (?) Hall	x	..	..
Zaphrentis ungula (?) Rominger	x	..	..
Zaphrentis wortheni Nicholson	x	..	..
Zaphrentis sp.	x	x	..
HYDROZOA.			
Dictyonema leroyensis Gurley	x	..	..
Stromatopora nodulata Nicholson	x	..	..
Stromatopora ponderosa Nicholson	x	x	..
Stromatopora sub-striatella Nicholson	x	..	..
Stromatopora sp.	x	x	..
Syringostroma columnaris Nicholson	x	..	..
*Syringostroma densa Nicholson	x	..	..
CRINOIDEA			
*Dolatocrinus cælatus (?) Miller and Gurley	x	..	..
*Dolatocrinus glyptus (Hall)	x	x	..
*Dolatocrinus greenei (?) Miller and Gurley	x	..	..

*Not collected by the writer.

12—S. G.—1,000.

	Columbus.	Delaware.	Olentangy.
*Dolatocrinus lacus Lyon	x	..	..
*Dolatocrinus liratus (Hall)	x	x	..
*Dolatocrinus major Wachsmuth and Springer	x	..	..
*Dolatocrinus ornatus Meek	x	..	..
Dolatocrinus sp.	x	..	..
*Megistocrinus depressus (Hall)	x	..	..
*Megistocrinus rugosus Lyon and Casseday	x	..	..
Megistocrinus spinulosus Lyon	x	..	..
Melocrinus sp.	..	..	x
BLASTOIDEA			
Codaster pyramidatus Shumard	x	..	..
Nucleocrinus venustus (?) Miller and Gurley	..	x	..
Nucleocrinus verneuili (Troost)	x	..	..
BRYOZOA			
Coscinium striatum Hall and Simpson	x	..	..
Cystodictya gilberti (Meek)	x	x	..
Cystodictya ovatipora (Hall)	..	x	..
Cystodictya sp.	x	..	x
Fenestella biseriata (?) Hall	..	x	..
Fenestella erectipora (?) Hall	x	..	..
Fenestella parallela (?) Hall	x	..	..
Fenestella sp.	x	x	x
Fistulipora substellata (?) Hall	x	..	..
Fistulipora vesiculata (Hall and Simpson)	..	x	..
Fistulipora sp.	x	x	..
Hederella canadensis Nicholson	..	..	x
Lichenalia sp.	x	..	..
Lioclema multiculeatum (Hall)	..	..	x
Monotrypa tenuis (Hall)	x	..	..
Monotrypa sp.	x	x	..
Nemataxis fibrosus Hall	x	..	..
Orthopora regularis Hall	..	x	..
Orthopora sp.	..	x	..
Polypora celsipora (Hall)	x	..	..
Polypora celsipora minima (?) (Hall)	x	..	..
Polypora flabelliformis (?) (Hall)	x	..	..
Polypora robusta (Hall)	x	..	..
Polypora sp.	x	..	..
Prismopora triquetra Hall	x	..	..
Semicoscinium bi-imbricatum (Hall)	x	..	..
Semicoscinium semi-rotundum (?) (Hall)	x	..	..
Stictopora sp.	x	..	..
Trematella arborea (?) (Hall)	..	x	..
Trematella sp.	..	x	x

*Not collected by the writer.

	Columbus.	Delaware.	Olentangy.
Unitrypa lata (Hall)	x	x	..
Unitrypa tegulata (Hall)	x	..	..
BRACHIOPODA			
Ambocœlia umbonata (Conrad)	..	x	x
Amphigenia elongata (Vanuxem)	x	..	..
Athyris spiriferoides (Eaton)	..	..	x
Athyris vittata indianaensis n. var	x	x	..
Atrypa reticularis (Linnæus)	x	x	x
Atrypa spinosa Hall	x	x	..
Camarospira eucharis Hall	x	x	..
Camarotœchia billingsi Hall	x	x	..
Camarotœchia carolina Hall	x	..	..
*Camarotœchia dotis Hall	..	x	..
Camarotœchia prolifica Hall	..	x	..
Camarotœchia sappho Hall	..	x	..
Camarotœchia tethys (Billings)	x	x	..
Camarotœchia sp.	x	x	..
Centronella glansfagea Hall	x	..	..
*Charionella scitula Hall	x	..	..
*Chonetes acutiradiatus Hall	x	..	..
Chonetes arcuatus Hall	x	..	..
Chonetes coronatus Conrad	..	x	x
Chonetes deflectus Hall	..	x	x
Chonetes hemisphericus Hall	x	..	..
Chonetes mucronatus Hall	x	x	..
Chonetes scitulus Hall	..	x	..
Chonetes setigerus (?) (Hall)	..	x	x
Chonetes yandellanus (?) Hall	x	..	..
Chonetes sp.	x	..	..
Chonostrophia reversa (Whitfield)	?	x	..
Crania crenistriata Hall	x	?	?
Crania sp.	x	..	..
Cryptonella lens Hall	x	..	..
Cyrtina crassa Hall	x	..	..
Cyrtina hamiltonensis Hall	x	x	..
Delthyris consobrina (d'Orbigny)	..	x	..
Delthyris raricosta Conrad	x	..	..
Eunella lincklæni Hall	x	x	..
Eunella sullivanti Hall	x	x	..
Eunella sp.	x	x	..
Leiorhynchus kelloggi Hall	..	x	x
Leiorhynchus laura (Billings)	..	x	x
Leiorhynchus limitare (Vanuxem)	..	x	..
Leiorhynchus sp.	..	..	x
Leptæna rhomboidalis (Wilckens)	x	x	..
Lingula ligea Hall	..	x	..
Lingula manni Hall	..	x	..

*Not collected by the writer.

	Columbus.	Delaware.	Olentangy.
Martinia maia (Billings)	..	x	..
Meristella nasuta (Conrad)	x	..	..
Meristella rostrata (?) Hall	x	..	..
Meristella sp.	x	..	..
Metaplasia disparalis (Hall)	x	..	..
Nucleospira concinna Hall	x	..	..
Orbiculoidea doria (Hall)	..	x	..
Orbiculoidea lodiensis (Vanuxem)	..	x	..
Orbiculoidea minuta (Hall)	..	x	..
Orbiculoidea sp.	..	..	x
Orthothetes chemungensis perversus (Hall)	..	x	..
*Orthothetes flabellum (Whitfield)	x	..	..
Orthothetes pandora (Billings)	x	x	..
Pentamerella arata (Conrad)	x	..	..
Pentamerella pavilionensis Hall	..	x	..
Pholidops patina Hall and Clarke	x	..	..
Pholidostrophia iowaensis (Owen)	x	x	..
Productella spinulicosta Hall	x	x	..
Reticularia fimbriata (Conrad)	x	..	..
Rhipidomella cleobis Hall	x	..	..
Rhipidomella livia (Billings)	x	?	..
Rhipidomella vanuexmi Hall	x	x	..
Rhipidomella sp.	x	x	..
*Rhynchonella (?) raricosta Whitfield	x	..	..
*Roemerela grandis (Vanuxem)	..	x	..
Schizophoria propinque Hall	x	..	..
Schizophoria striatula (Schlotheim)	..	..	x
Spirifer acuminatus (Conrad)	x	..	..
Spirifer audaculus (Conrad)	..	x	..
Spirifer audaculus macronatus Hall	..	x	..
Spirifer divaricatus Hall	x	..	..
Spirifer duodenarius (Hall)	x	..	..
Spirifer fornacula Hall	x	..	..
Spirifer gregarius Clapp	x	..	..
Spirifer grieri Hall	x	..	..
Spirifer lucasensis n. sp	..	x	..
Spirifer macrus Hall	x	x	..
Spirifer macrothyris Hall	x	..	..
Spirifer manni Hall	x	..	..
*Spirifer marcyi Hall	..	x	..
Spirifer pennatus (Atwater)	..	..	x
*Spirifer segmentum Hall	x	..	..
Spirifer varicosus Hall	x	..	..
Spirifer sp.	x	x	x
Strophalosia cf. truncata (Hall)	x	..	..
Stropheodonta concava Hall	x	x	x
Stropheodonta demissa (Conrad)	x	x	x

*Not collected by the writer.

	Columbus.	Delaware.	Olentangy.
Stropheodonta hemispherica Hall	x	x	..
Stropheodonta inæquiradiata Hall	x	..	..
Stropheodonta inæquistriata (Conrad)	x	x	..
Stropheodonta parva (?) Hall	x	x	..
Stropheodonta patersoni Hall	x	..	..
Stropheodonta perplana (Conrad)	x	x	x
Stropheodonta sp.	..	x	..
Strophonella ampla Hall	x	..	..
PELECYPODA			
Actinopteria boydi (Conrad)	x	..	x
Actinopteria sp.	x	..	?
Aviculopecten cleon Hall	x	?	?
*Aviculopecten æquilateris Hall	..	x	..
Aviculopecten exactus (?) Hall	..	x	..
Aviculopecten fasciculatus Hall	..	..	x
*Aviculopecten parilis (Conrad)	x	x	..
Aviculopecten cf. pecteniformis (Conrad)	x	..	..
Aviculopecten princeps (Conrad)	x	x	..
Aviculopecten sp.	x	x	x
*Clinopistha antiqua Meek	x	..	..
Conocardium cuneus (Conrad)	x	x	..
Conocardium cuneus attenuatum (Conrad)	x	..	..
Conocardium cuneus subtrigonale d'Orbigny	x	..	..
Conocardium ohioense Meek	x	..	..
Conocardium sp.	x	x	..
*Cypricardella major (Hall)	..	x	..
Cypricardella tenuistriata (Hall)	..	x	..
Cypricardinia indenta (?) Conrad	..	..	x
Glossites teretis (?) Hall	x	..	..
Glyptocardia speciosa Hall	..	..	x
Glyptodesma erectum (Conrad)	..	x	..
Glyptodesma occidentale Hall	x	..	..
Goniphora cf. hamiltonensis Hall	x	..	..
Grammysia arcuata (Conrad)	x	..	..
Grammysia bellatula Hall	..	..	x
Grammysia bisulcata (Conrad)	..	x	x
Grammysia ovata Hall	..	x	..
Grammysia secunda (?) Hall	x	..	..
Grammysia subarcuata (?) Hall	x	..	..
Leiopteria rafinesquii Hall	..	x	x
Limopteria pauperata Hall	x	..	..
Macrodon sp.	..	x	..
*Modiomorpha complanata Hall	..	x	..
Modiomorpha concentrica (Conrad)	x	..	..
Modiomorpha subalata (Conrad)	..	..	x
Modiomorpha sp.	x	..	x
Mytilarca cf. carinata Hall	..	..	x

Not collected by the writer.

	Columbus.	Delaware.	Olentangy.
Mytilarca percarinata Whitfield	x	..	..
Mytilarca sp.	..	x	..
Nucula niotica Hall and Whitfield	x	..	..
Nucula sp.	x	..	..
Nuculites triqueter Conrad	..	..	x
Nyassa arguta Hall	..	x	..
*Panenka alternata Hall	x	..	..
Palaeoneilo (?) sanduskiensis n. sp	..	x	..
Paracyclas elliptica Hall	x	x	..
Paracyclas lirata (Conrad)	..	x	..
Paracyclas ohioensis Meek	x	..	..
Paracyclas sp.	x	..	..
Pholidella sp.	..	..	x
Plethomytilus ponderosa Hall	x	..	..
Pterinea flabellum (Conrad)	x	..	x
*Pterinea similis Whitfield	x	..	..
Ptychopteria (?) sp.	x	..	..
Sanguinolites (?) sanduskiensis Meek	x	..	..
Schizodus appressus (Conrad)	x	..	x
Schizodus contractus Hall	x	..	..
Schizodus tumidus Hall	x	..	..
Schizodus sp.	..	x	..
Solemya vestuta Meek	x	..	..
Sphenotus cuneatus (Conrad)	..	x	x
GASTROPODA			
Bellerophon acutilira (?) Hall	x	..	..
Bellerophon hyalina Hall	x	..	..
Bellerophon lyra Hall	..	..	x
Bellerophon newberryi Meek	x	..	..
Bellerophon pelops Hall	x	?	..
Bellerophon rotalinea (?) Hall	x	..	..
Bellerophon sp.	x	x	x
Callonema bellatulum (Hall)	x	..	..
Callonema clarki Nettelroth	x	..	..
Callonema initator Hall and Whitfield	x	..	..
Callonema lichas (Hall)	x	..	..
Callonema sp.	x	..	..
Cœlidium strebloceras (?) Clarke	x	..	..
Cyclonema crenulatum Meek	x	..	..
Cyclonema sp.	x	..	..
Cyrtonella mitella Hall	..	..	x
Dentalium martini Whitfield	x	..	..
Euomphalus decewi Billings	x	x	..
Isonema depressum Meek and Worthen	x	..	..
Isonema humile Meek	x	..	..
Loxonema gracillium Whiteaves	x	..	..
Loxonema læviusculum Hall	x	..	..

*Not collected by the writer.

	Columbus.	Delaware.	Olentangy.
Loxonema parvulum Whitfield	x	..	..
Loxonema pexatum Hall	x	..	..
Loxonema pexatum obsoletum Hall	x	..	..
Loxonema robustum Hall	x	..	..
Loxonema sicula (?) Hall	x	..	..
Loxonema sp.	x	..	..
Macrocheilus hebe (?) (Hall)	x	..	..
Macrocheilus macrostoma (Hall)	x	..	..
Macrocheilus prisca (Whitfield)	x	..	..
Macrocheilus sp	x	..	..
Murchisonia desiderata Hall	x	..	..
Murchisonia desiderata var. Hall	x	..	..
Murchisonia eversolensis n. sp	x	..	..
Murchisonia intermedia n sp	x	..	..
Murchisonia leda Hall	x	..	..
Murchisonia maia Hall	x	..	..
Murchisonia quadricarinata n. sp	x	..	..
Murchisonia sp.	x	..	..
Naticopsis æquistriata Meek	x	..	..
Naticopsis comperta Hall	x	..	..
Naticopsis lævis Meek	x	..	..
Naticopsis sp.	x	..	..
Orthonema newberryi Meek	x	..	..
Palæotrochus kearneyi (Hall)	x	..	..
Platyceras attenuatum Hall	x	..	..
Platyceras blatchleyi Kindle	x	..	..
Platyceras bucculentum Hall	x	x	..
Platyceras carinatum Hall	x	x	..
Platyceras cymbium Hall	x	..	..
Platyceras dumosum Conrad	x	x	..
Platyceras erectum (Hall)	x	x	x
Platyceras multispinosum Meek	x	..	..
Platyceras nodosum Conrad	..	x	..
*Platyceras rarispinosum Hall	x	..	..
Platyceras rictum Hall	x	..	..
*Platyceras squalodens Whitfield	x	..	..
Platyceras thetis Hall	x	..	..
Platyceras sp.	x	x	..
Platystoma lineatum Conrad	x	..	..
Platystoma subglobosa n. sp	x	..	..
Pleurotomaria adjutor Hall	x	..	..
Pleurotomaria cancellata n. sp	x	..	..
Pleurotomaria capillaria (?) Conrad	..	..	x
Pleurotomaria dublinensis n. sp	x	..	..
Pleurotomaria hyphantes Meek	x	..	..
Pleurotomaria insolita Hall	x	..	..
Pleurotomaria lucina Hall	x	..	..

*Not collected by the writer.

	Columbus.	Delaware.	Olentangy.
Pleurotomaria plena Hall	x	..	..
Pleurotomaria procteri Nettelroth	x	..	..
Pleurotomaria regulata (?) Hall	x	x	..
Pleurotomaria rotalia Hall	..	..	x
Pleurotomaria sciotoensis n. sp	x	..	..
Pleurotomaria sp.	x	x	x
*Porcillia scioto Hall and Whitfield	x	..	..
Porcillia hertzeri Hall	..	x	..
Pseudophorus antiquus Meek	x	..	..
Strapharollus corrugatus n. sp	x	..	..
Strophostylas varians Hall	x	..	..
Trochonema meekanum Miller	x	..	..
Turbo shumardi Verneuil	x	..	..
PTEROPODA			
Coleolus crenatocinctus Hall	x	..	..
Coleolus sp.	x	..	..
*Conularia elegantula Meek	..	x	..
Styliola fissurella Hall	..	..	x
Tentaculites scalariformis Hall	x	x	..
CEPHALOPODA			
Agoniatites discoideus (Hall)	x	..	..
*Anarcestes cf. lateceptatus Beyrich	x	..	..
Cyrtoceras cretaceum Whitfield	x	..	..
Cyrtoceras metula (?) Hall	x	..	..
Cyrtoceratites ohioensis Meek	x	..	..
Discites ammonis (?) Hall	..	x	..
*Discites inopinatus Hall	x	..	..
*Gomphoceras amphora Whitfield	x	..	..
*Gomphoceras crenatum Hall	x	..	..
Gomphoceras eximium Hall	x	..	..
*Gomphoceras gomphus Hall	x	..	..
*Gomphoceras hyatti Whitfield	x	..	..
*Gomphoceras impar Hall	x	..	..
*Gomphoceras mitra Hall	x	..	..
Gomphoceras plenum Beecher	x	..	..
*Gomphoceras sciotense Whitfield	x	..	..
Gomphoceras sp.	x	x	..
Gyroceras columbiense Whitfield	x	..	..
Gyroceras cyclops Hall	x	..	..
*Gyroceras seminodosum Whitfield	x	..	..
Gyroceras sp.	x	x	..
*Gyroceratites inelegans Meek	x	x	..
Gyroceratites ohioensis Meek	x	x	..
*Orthoceras dagon Hall	x	..	..
Orthoceras eriensis (?) Hall	..	x	..
*Orthoceras molestum Hall	x	..	..

*Not collected by the writer.

	Columbus.	Delaware.	Olentangy.
Orthoceras nuntium Hall	x	..	..
Orthoceras ohioensis Hall	x	x	..
Orthoceras sirpus Hall	x	..	..
Orthoceras thoas Hall	x	..	..
*Orthoceras winchelli Meek and Worthen	x	..	..
Orthoceras sp.	..	x	x
*Tornoceras mithrax (Hall)	x	..	..
*Trematoceras ohioense Whitfield	x	..	..
CRUSTACEÆ			
Barychilina sp.	..	..	x
Bollia sp.	..	..	x
Bythocypris indianensis (?) Ulrich	..	..	x
Bythocypris cf. punctatus Ulrich	..	..	x
Chasmops anchiops Green	x	..	..
Chasmops calypso Hall	x	..	..
Coronura diurus (Green)	x	..	..
*Coronura ohioensis Meek	x	..	..
Dalmanites sp.	x	..	..
Odontocephalus ægeria Hall	x	..	..
Odontocephalus bifidus Hall	x	..	..
Phacops cristata Hall	x	..	..
Phacops rana (Green)	..	x	x
Phacops sp.	x	x	..
Proetus crassimarginatus Hall	x	..	..
Proetus planimarginatus Meek	x	..	..
Proetus rowii (Green)	x	x	..
Proetus welleri n. sp	x	..	..
Proetus sp.	x	x	..
VERTEBRATA			
PISCES			
*Acanthaspis armata Newberry	x	x	..
*Acantholepis fragilis Newberry	x	x	..
*Asterosteus stenocephalus Newberry	..	x	..
*Cladodus prototypus Eastman	x	..	..
*Coccosteus occidentalis Newberry	..	x	..
*Coccosteus spatulatus Newberry	..	x	..
*Coelolepis sp.	x	..	..
*Cyrtacanthus dentatus Newberry	x	..	..
*Dinichthys precursor Newberry	x	..	..
*Machæracanthus major Newberry	x	x	..
*Machæracanthus peracutus Newberry	x	x	..
*Machæracanthus sulcatus Newberry	x	x	..
Macropetalichthys rapheidolabis Norwood and Owen	x	x	..
Onychodus sigmoides Newberry	x	x	..

*Not collected by the writer.

	Columbus.	Delaware.	Olentangy.
*Palæomylus crassus (Newberry)	x	x	..
*Palæomylus frangens (Newberry)	x	x	..
*Protitanichthys fossatus Eastman	..	x	..
*Psammodus antiquus Newberry	x	..	..
*Rhynchodus secans Newberry	x	x	..
*Thelodus sp.	x	..	..

DISCUSSION OF THE COLUMBUS FAUNA.

An inspection of this table shows at a glance the extraordinary importance of the Coral element in the Columbus limestone, and yet many of the specimens collected were so indefinite that no attempt was made to identify them.

Attention has so frequently been called to the fossil Coral reef at the Falls of the Ohio that it has become a classic locality in geology. A similar reef extends along the Scioto River for a distance of nearly twenty miles, although unfortunately it is not so strikingly exposed as the one beyond the Cincinnati anticline. In this bed the Corals occur in the utmost profusion, often imbedded in a matrix composed of fragments resulting from their own destruction, some still maintaining their original position and remaining in an excellent state of preservation. Coral reefs also occur in the Onondaga limestone of New York,[1] in the Devonian of Belgium, and some of the same reef building species are identified even in Australia,[2] but nowhere are they known to be better developed than on the east and west sides of the Cincinnati arch. In Ontario the best development of the Devonian Corals is perhaps in the vicinity of Villa Nova,[3] where extensive deposits occur made up largely of the skeletons of these animals. Along the Kwataboahegan River, southwest of James Bay, great numbers of Corals occur[4] and here again the same species are found as in the central Ohio region. In southern Illinois, however, where the Onondaga phase is so well developed,[5] the Coral element is reduced to a few species of rather rare occurrence, in a fauna rich in species[6] of this age. The Devonian of South America is almost destitute of Corals,[7] while the middle Devonian of western Europe and

*Not collected by the writer.

[1]For a discussion of Paleozoic Coral Reefs, see Grabau, A. W., *Bull. Geol. Soc. Am.*, Vol. XIV, 1903, pp. 337-352.

[2]Jack, Robert L. and Robert Etheridge, Jr., *Geol. and Pal. of Queensland and New Guinea*, 1892, p. 48.

[3]Parks, W. A., 12th Rept. *Ont. Bur. of Mines*, 1903, pp. 142, 143.

[4]Parks, W. A., 13th Rept. *Ont. Bur. of Mines*, 1904, p. 181.

[5]Savage, T. E., *Ill. State Geol. Surv.*, Bull. No. 8, 1907, pp. 106, 113, 114.

[6]Weller, Stuart, *Jour. Geol.*, Vol. V, 1897, pp. 626-632.

[7]Katzer, Friedrich, *Grundzüge der unteren Amazonasgebietes*, 1903, p. 192, pl. 9, (Leipzig).

Also Knod, Reinhold, *Neues Jahrbuch*, Vol. XXV, (Beilage Band), 1908, p. 574.

of Siberia has a rich Coral fauna[1]. This certainly has a significant bearing on the direction of migration of this element of the fauna, and especially since the lower Devonian faunas of Gaspé are also poor in its possible forebearers[2].

Extensive Coral reefs occur in the Silurian rocks of Wisconsin[3] and Iowa[4], and it is a fact worthy of note that among the 16 genera listed in the above tabulation, 11 genera were also represented in the Silurian, while even the Stromatoporoids which are so abundant in the Devonian Coral beds near Columbus, are represented in these older deposits. If the Silurian Corals retreated northward upon the withdrawal of the sea, and there continued to thrive in some as yet unknown province,[5] just such a relationship would be expected between the old fauna and the new which would return with a readvance of the sea. This northern origin of the Corals is still further supported by the fact that at Cayuga, Ontario, 52 species occurring in the Oriskany sandstone are common to the Onondaga limestone, while in New York state and Maryland only 7 bear this relation.[6] Of this number of common species 19 are Corals. Weller has suggested that the commingling of Onondaga and Oriskany forms at this most northern point of the Eastern Continental area, where the latter fauna is known, may indicate the locality where "the Corniferous (Onondaga) fauna first came in contact with the Oriskany."[7]

The vicinity of Columbus has long been known as a representative region for the Onondaga fauna, and in no other phase is this so well illustrated as among the species of Brachiopods which may be found here; in fact almost any species which occurs in any other part of the Eastern Continental area, together with some forms at one time thought to be exclusively Hamilton, may be expected in the Columbus limestone. The great majority of the species indicate the close relationship to the Ontario and New York expressions of the fauna that their direct communication leads one to expect. Certain species, however, such as *Cyrtina hamiltonensis*, *Stropheodonta perplana*, *Spirifer duodenarius*, *Spirifer macrothyris*, etc., together with other forms closely allied to Columbus species, occur in the Upper Oriskany of southern Illinois,[8] while *Stropheodonta perplana*, *Chonetes mucronatus*, *Chonostrophia reversa*, etc., are found also in the Oriskany of Tennessee,[9] and in South America a kindred fauna, with some of these very species, lived in the lowest Devonian (Oriskany?).[10]

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[1]Lebedew, N., *Mem. du Comité Géologique*, Vol. XVII, No. 2, 1902, pp. 1-130, 137-180.
[2]Clarke, J. M., *N. Y. State Mus. Mem.* 9, 1908, pp. 243-252.
[3]Chamberlin, T. C., *Geol. Surv. Wis.*, Vol. II, 1877, pp. 349-371.
[4]Calvin, Samuel, *Geol. Surv. Ia.*, Vol. V, 1896, pp. 79-81.
[5]Weller, Stuart, *Jour. Geol.*, Vol. X, 1902, p. 429.
[6]Hall, James, 8th Ann. Rept. *N. Y. State Geol.*, 1888 (1889), pp. 51-54.
[7]*Op. cit.*, p. 430.
[8]Savage, T. E., *Op. cit.*, p. 113.
[9]Schuchert, Charles, *Am. Jour. Sci.*, 4th Ser., Vol. VII, 1899, pp. 430-432.
[10]Katzer, Friedrich, *Op. cit.*, pp. 192-196, 202, 210, 211, pls. 10, 11.
Also Knod, Reinhold, *Op. cit.*, pp. 573-574.

Among the species above referred to it is worthy of note that *Spirifer duodenarius* has been found only in the upper ten feet of the Columbus limestone. *Spirifer macrothyris* is found in the middle and lower parts of the formation, and at Harrisburg, south of Columbus, it is one of the most plentiful fossils in a rock that is nothing but a mass of Brachiopod remains. At Sandusky the species was not found at all nor is it reported from the James Bay region, although it occurs at Cayuga, Ontario. *Chonostrophia reversa* has been questionably identified in the very top layers of the Columbus, although it is a common fossil in the overlying Delaware limestone. On the other hand, *Spirifer gregarius*, which is such an abundant fossil in the Columbus limestone, has not been identified in the middle Devonian fauna of southern Illinois. The species occurs in Ontario, and on the islands of Lake Erie and at Marblehead it is the dominant form in the very base of the formation, while in the central part of the state it does not become abundant until a little above the middle of the formation. *Meristella nasuta* is another species which occurs in Ontario, even in the James Bay region, and in central Ohio is the most important fossil of a distinct zone just below the middle of the formation. This fossil, like *Spirifer gregarius*, is found as far south as the Falls of the Ohio but is not known in southern Illinois. Other species, such as *Camarospira eucharis*, *Cyrtina crassa*, *Metaplasia disparalis*, etc., show the same relation, but they are among the rare species of the Columbus fauna.

It seems rather doubtful whether the Eastern Border area had a direct connection with the Eastern Continental area during Onondaga time. At least there is no indication of migration in that direction, since the fauna of this age is not represented as such in the Gaspé region.[1] There is, however, an association of Brachiopods in the Grande Grève limestone (Oriskany) which is also a part of the Columbus fauna. These are *Centronella glansfagea*, *Reticularia fimbriata*, *Delthyris raricosta*, *Stropheodonta parva*, *Stropheodonta patersoni*, and *Strophonella ampla*. The occurrence of most of these species in the Upper Oriskany of southern Illinois is certainly suggestive of the route which they followed in reaching the Ohio region, although some of them are among those which pass from the Oriskany (transition beds) to the Onondaga at Cayuga, Ontario. The few Onondaga Corals collected at Lake Memphremagog[2] and near the city of Quebec seem to suggest that these patches of Middle Devonian are outliers from the great deposits to the southwest and not indicators of a former connection between this area and the Eastern Border area.

Most of the Brachiopods of the Columbus limestone have a wide distribution throughout the area of which it forms a part. The new

[1]Clarke, J. M., *Op. cit.*, p. 251.

[2]Ami, Henry M., Ann. Rept. *Geol. Surv. Can.*, Vol. VII, N. S., 1894, p. 157 J.

conditions developed in an advancing sea are eminently favorable for the rapid evolution of life; hence it is probable that many species have not migrated far from their initial locality, while in other cases the antecedent faunas may be obscured by immigration from other localities. Possibly the great majority of the species of this vigorous fauna, from whatever source, spread over the newly acquired territory contemporaneous with the advance of the sea, and only the few less inclined to migrate remained as a vanguard and thus indicate the direction from which others have come.

The Pelecypod element is hardly so useful a means of comparison. It is well represented, both to the north and to the south, and perhaps better in either direction than in Ohio. Unfortunately, those of the farther north have not been fully determined as yet. A rather close relationship to the Eastern Border area is indicated by the fact that, of the 19 genera definitely identified from the Columbus limestone, about a dozen genera are common to the Grande Grève (Oriskany) limestone, among which *Schizodus appressus* and *Conocardium cuneus* are species represented in both regions. At least 8 of the Ohio genera are represented in the early Devonian of Brazil,[1] and several of the species are closely allied. Essentially the same relation obtains in Bolivia[2].

It is to be regretted that our knowledge of the faunas of the few but important outcrops of Middle Devonian in Mississippi, Alabama, and Georgia is too meager to be of assistance in indicating the direction of migration of these faunas, and the deposits of southern Illinois have not as yet shown a very important Pelecypod element. While there are a number of species represented, Pelecypods are not among the fossils usually abundant in the Columbus limestone. One species, however, may have a definite bearing of a character different from that indicated above; this is *Paracyclas elliptica,* which is one of the more common Columbus Pelecypods. In north central Europe the genus is represented in the upper part of the Lower Devonian.[3] It is to be noted that while this species occurs in southern Illinois, not even the genus is represented in the Gaspé region or in South America. *Plethomytilus ponderosa* and *Mytilarca percarinata* are also probably found to the north, but so far not in Indiana, Illinois or Kentucky, and again not even the genera in South America, although *Mytilarca* is represented in the Gaspé region.

The Gastropod fauna is exceptionally rich and specimens of the larger forms are abundant, especially in the middle and upper part of the formation. A large number of species, however, were found only in the limited cherty layers (the Gastropod zone) below the middle of

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[1]Schuchert, Charles, *Jour. Geol.*, Vol. XIV, 1906, pp. 744, 745.
[2]Knod, Reinhold, *Op. cit.*, pp. 572, 573.
[3]Kayser, Emanuel, *Lehrbuch der Geologie*, dritte auflage, teil 2, 1908, p. 184, pl. 14.

the formation. Of the 20 genera in the above list, four are also known in the Lower Devonian of South America and at least one of these, *Strophostylas varians*, is identical. *Euomphalus decewi*, *Loxonema robusta*, *Murchisonia desiderata*, etc., are common to Ohio and to the James Bay region, but are not known in southern Illinois.

The Cephalopods are an important element in this fauna and are distributed throughout the formation. They are also among the abundant forms of the James Bay region[1], and at least *Orthoceras* is common to this and the Ohio region. The southern Illinois fauna contains but a few genera of Cephalopods, and except *Gomphoceras*, these are all rare. Three genera occur in the Gaspé region, but the Lower Amazon has not yielded a single Cephalopod, and Bolivia only one species of the genus *Orthoceras*.[2]

The occurrence of the first Goniatites known in America is an event of much importance. Three genera—*Tornoceras*, *Agoniatites* and *Anarcestes*—are represented with one species each. The Goniatites have their best early development in central Europe,[3] where they are represented by about a half dozen genera in the Middle and Lower Devonian, with a few even in the Silurian.

The Trilobites are remarkably similar throughout. *Dalmanites* and *Phacops* are among the common genera in the Devonian of the Lower Amazon, of Gaspé, and of Ohio. *Phacops cristata*, a common fossil of the Columbus limestone and the same horizon northward, occurs also in the Oriskany of Tennessee and southern Illinois. *Odontocephalus* is perhaps indigenous to the region and an evolution product of the Oriskany, since its nearest relative seems to be in that fauna. The almost universal distribution of the Trilobites has been observed at other horizons, especially in the Cambrian, and by way of explanation it has been suggested that their larvæ composed a part of the Plankton which ocean currents quickly carried to all parts of the sea.[4] Trilobites are thus well suited to correlation purposes, but give little assistance in an attempt to discover the source of a fauna.

Fish remains have been found in the middle of the formation and continue to be important throughout the remainder of the Ohio Devonian. The same genera and many of the same species occur in the Delaware as in the Columbus limestone. On account of the association of the early fishes with Eurypterids and other evidences of fresh water or littoral conditions, it has been suggested[5] that the Ordovician and Silurian fishes lived in the rivers and fresh water lakes. The first ap-

[1]Parks, W. A., *Op. cit.*, pp. 188-190.
[2]Knod, Reinhold, *Op. cit.*, pp. 502, 503.
[3]Kayser, Emanuel, *Op. cit.*, pp. 187, 189, pls. 17, 19; also Barrande, Joachim, *Système Silurien du centre de la Bohême*, Vol. II, 1865, pp. 28-42, pls. 1-12, etc.
[4]Kayser, Emanuel, *Op. cit.*, p. 78.
[5]Chamberlin, T. C., *Jour. Geol.*, Vol. VIII, 1900, pp. 400-412.

pearance of marine fishes in North America seems to have been in the Gaspé region during Lower Devonian time.[1] It is to be noted, however, that only one genus, and of that the species also, *Machaeracanthus sulcatus*, is common to the Middle Devonian of the Eastern Continental region. At least one of the common Ohio species, *Macropetalichthys rapheidolabis*, is found in the Devonian southward of James Bay[2] and two genera occur in the Devonian of Spitzbergen.[3]

Eastman's list of the fishes from the Eastern Continental area includes all of the genera known to occur in the Eifel and Bohemia regions of Europe and five in addition, which seems to indicate that this region is nearer to the original source of this important element of the fauna than either of the latter regions. Fish remains are among the rare fossils of southern Illinois. In Bolivia such fossils are said to occur[4] although up to the present none have been specifically identified from the South American region.

FAUNAL ELEMENTS OF THE COLUMBUS.

As a whole, then, this fauna may be considered as composed of two elements—a southern[5] somewhat related to the faunas of the older sediments of the Gaspé region and of the Lower Amazon, Bolivia, and Argentine, which at least in part had reached Tennessee and southern Illinois by the latter part of the Oriskany, together with other species which may have originated in some nearer territory; and a northern[6] much more distinctive element consisting especially of the Corals, the Cephalopods and the fishes, which bear such relations to the faunas of northern and central Europe as to make it seem certain that these found entrance by way of the north, possibly along the present shallows[7] connecting Europe and America through Iceland and Greenland. The Hudson Bay is a shallow epi-continental sea in a region of low relief and great stability—a neutral region. It may therefore have persisted throughout a long period of time and perhaps is even the remnant of the old northern Paleozoic sea through which these faunas found entrance to the Eastern Continental sea. This is suggested not only by the deposit of Devonian in the James Bay region but by the remnants on Southampton Island and others less perfectly known to the north.[8] As Clarke's studies have shown, the Onondaga fauna is undifferentiated

[1]Eastman, C. R., *N. Y. State Mus. Mem.* 10, 1907, p. 13; *Geol. Surv. Ia.*, Vol. XVIII, 1908, pp. 275, 276.

[2]Whiteaves, J. F., *Geol. Surv. Can.*, Rept. of Prog., 1875-76, (1877), pp 319, 320.

[3]Eastman, C. R., *Op. cit.*, p. 193.

[4]Knod, Reinhold, *Op. cit.*, p. 574.

[5]Ulrich, E. O., and Charles Schuchert, *N. Y. State Mus. Bull.* 52, 1902, p. 652.

[6]Weller, Stuart, *Jour. Geol.*, Vol. X, 1902, p. 429.

[7]Chamberlin, T. C., *Jour. Geol.*, Vol. VI., 1898, p. 603.

[8]Schuchert, Charles, *Am. Geol.*, Vol. XXXII, 1903, p. 155.

in the Eastern Border region. But more than that, it lacks the two most distinctive elements of the fauna, the Corals and Cephalopods, and so many others that if a Connecticut channel[1] was functional during Onondaga time, certainly this portion of the fauna could not have found entrance to the Eastern Continental sea by way of Gaspé. Perhaps rather the species which came from the Eastern Border region migrated south and came in by the same route as did those coming from South America.

The fauna shows pretty clearly that there could have been no immediate connection with the Devonian sea of Iowa and the northwest. In fact it is even probable that no such sea existed while the Onondaga was being deposited in the Eastern Continental region.

The similarity of some species, and the possible identity of others, of the Western Continental area[2] to those occurring in the Eastern Continental area makes it seem that a possibility of migration between the two regions may have existed.[3] Schuchert has suggested a southern connection through Central America,[4] and this would seem to be substantiated by the work of the Mexican Geological Survey[5] as also by the map of North America published by the Geological Congress.[6] But these identifications of Devonian are not beyond question, as the deposits in general are highly metamorphosed; it is reasonably certain, however, that the Mississippian sea crossed at about this point.[7]

DISCUSSION OF THE DELAWARE AND OLENTANGY FAUNA.

The fauna of the Delaware limestone and the Olentangy shale is exceedingly poor as compared with that of the Columbus limestone. This is true not merely of the number of species but of the individual specimens as well. The Delaware limestone begins with a zone, often a true shale, carrying among others the most distinctive fossil, *Leiorhynchus limitare*, of the Marcellus shale of New York. This is more characteristic of the Columbus region, although it has been observed in the northern part of the state as well. Of the Delaware limestone proper the fauna is mostly a remnant of the Columbus limestone species which have withstood the Marcellus conditions. In addition to these species, which are those usually common to the Onondaga and

[1]Schuchert, Charles, *Op. cit.*, pp. 155, 156, pls. 20 and 21.
Also *Geol. Surv. Ia.*, Vol. XVIII, 1908, pl. 14.

[2]Walcott, Charles D,. *Monog. U. S. Geol. Surv.*, Vol. VIII, 1884, pp. 99-211, pls. 13-17.

[3]In this connection see also Kindle, E. M., *U. S. Geol. Surv.* Bull. No. 391, 1909, pp. 1-36, pls. I-X.

[4]*Geol. Surv. Iowa*, Vol. XVIII, 1908, pls. 14-16.

[5]Aguilera, José G., *Boletin del Instute Geológico de Mexico*, Nos. 4, 5 and 6, p. 198, Map opp. p. 270.

[6]Gannett, H. and B. Willis, *Carte Géologique de l'Amérique du Nord. Congrès Géologique International Xe Session*, 1906.

[7]Sapper, K., *Peterman's Geographische Mitteilungen*, Vol. LII, 1906, p. 237.

Hamilton in the Eastern Continental region, there are also certain other forms, such as *Ambocœlia umbonata*, *Chonetes coronatus*, *Chonetes scitulus*, *Delthyris consobrina*, *Leiorhynchus laura*, *Spirifer audaculus*, *Grammysia bisulcata*, *Nyassa arguta*, *Sphenotus cuneatus*, etc., which are rather distinctively Hamilton. The Olentangy shale, which forms the upper member of the Middle Devonian in Ohio, is usually barren of fossils except for the local Crinoidal layer at Delaware. In the Sandusky region, however, these shales, especially the marly limestone near the top and the crystalline limestone at the very top, carry a considerable fauna. The abundant forms of this upper zone are: *Spirifer pennatus*, *Chonetes deflectus*, *Leiorhynchus kelloggi*, *Stropheodonta demissa*, *Stropheodonta perplana*, *Schizophoria striatula*, *Grammysia bisulcata*, *Modiomorpha subalata*, *Phacops rana*, etc., decidedly the Hamilton fauna of New York and Ontario.

The Hamilton is in the main a derivative from the Onondaga fauna, but it also possesses certain foreign elements which are equally charactersitic. Among these latter forms are *Chonetes coronatus*, *Tropidoleptus carinatus*, and *Ambocœlia umbonata*, which are known in the early Devonian of Bolivia, Brazil, and Argentine,[1] while a single specimen of *Tropidoleptus carinatus* is known from the Oriskany of Maryland.[2] Other species such as *Schizophoria striatula* and *Athyris spiriferoides* (*concentrica*) are represented in the Middle Devonian of Europe and may have migrated west from that locality. Schuchert has suggestd that the European element may have entered by way of the Connecticut trough,[3] but his more recent paleogeographic map[4] would seem to indicate that he has abandoned the idea of a Connecticut trough for the Hamilton.

Rocks of Hamilton age probably occur in the vicinity of James Bay. A few species, among which is *Spirifer pennatus*, have been collected in a red clay[5] of that region and furnish about the only evidence at present known which seems to indicate the development of these beds in that locality. In southern Illinois the Hamilton beds are well represented and contain a characteristic fauna.[6] The absence of some species, however, especially among the Coelenterata and the Mollusca, is certainly in contrast to the Ohio fauna.

The relationships of the South American Devonian faunas are rather with the Oriskany and as a source of certain of the Onondaga forms, but a decided Hamilton relation is also indicated by the fauna of the

[1]Knod, Reinhold, *Op. cit.*, pp. 545-551. Also Ulrich, Arnold, *Neues Jahrbuch*, Vol. VIII, (Beilage Band), 1893, pp. 73-75, 79, 80, pls. IV, V. Also Bordenberger, W., *Zeit. d. Deut. geol. Ges.*, Vol. XLVII, 1896, pp. 748-754.

[2]Schuchert, Charles, *Jour. Geol.*, Vol. XIV, 1906, p. 733.

[3]*Am. Geol.*, Vol. XXXII, 1903, pp. 156, 162.

[4]*Geol. Surv. Iowa*, Vol. XVIII, 1908, pl. 15.

[5]Whiteaves, J. F., *Am. Geol.*, Vol. XXIV, 1899, p. 231.

[6]Savage, T. E., *Op. cit.*, pp. 105, 114, 115.

upper beds. This is especially shown by the Brachiopods and the Trilobites,[1] and less clearly in the Pelecypods.

The species common to the Eastern Continental and the Interior Continental areas are such as have a wide range and distribution. The real mingling of these faunas probably did not take place until late Hamilton (Tully) time,[2] and then apparently along the route suggested by Schuchert, that is, past the Milwaukee region[3] and through the Michigan basin.

THE NORTHWESTERN DISTRICT.

In northwestern Ohio a two fold division of the Middle Devonian is observed, the lower consisting of the Columbus limestone and the upper of the Traverse formation, which latter is regarded as the equivalent of the Delaware limestone and the Olentangy shale to the east of the Cincinnati anticline. The Columbus limestone is quite fossiliferous, especially in the upper part; the lower being less fossiliferous, as is also the case in central Ohio. The small number of species listed from this formation in the following table indicates rather the few outcrops than the paucity of its fauna.

FAUNA OF THE MIDDLE DEVONIAN OF THE NORTHWESTERN DISTRICT.

INVERTEBRATA.

RHIZOPODA.

	Columbus.	Traverse.
Calcisphæra robusta Williamson	x	?

ANTHOZOA.

Acervularia davidsoni Edwards and Haime	x	x
Aulopora serpens Goldfuss	..	x
Cladopora canadensis Rominger	..	x
Cladopora frondosa Nicholson	..	x
Cladopora tela Davis	x	..
Cladopora sp.	..	x
Cyathophyllum rugosum Edwards and Haime	x	..
Cyathophyllum sp.	..	x
Cystiphyllum vesiculosum Goldfuss	..	x
Diphyphyllum panicum (Winchell)	..	x
Favosites alpinensis Winchell	..	x
Favosites arbusculus Hall	..	x
Favosites emmonsi Rominger	x	..
Favosites hamiltoniæ Hall	..	x
Favosites hemisphericus (Troost)	x	x

[1]Katzer, F., *Op. cit.*, p. 199, pl. 15.
[2]Weller, Stuart, *Jour. Geol.*, Vol. XVII, 1909, pp. 265, 266, 268.
[3]*Am. Geol.*, Vol. XXXII, 1903, pp. 149, 150, pl. 21.

	Columbus.	Traverse.
Favosites nitellus Winchell	..	x
Favosites placentus Rominger	..	x
*Favosites polymorphus Goldfuss	x	..
Favosites radiciformis (?) Rominger	..	x
Favosites sp.	..	x
Heliophyllum halli Edwards and Haime	..	x
Romingeria umbellifera Billings	..	x
Streptelasma ungula Hall	..	x
Strombodes alpinensis Rominger	..	x
Syringopora sp.	..	x
Trachypora elegantula Billings	..	x
Zaphrentis cornicula Edwards and Haime	x	..
Zaphrentis gigantea (?) Rafinesque	x	..
Zaphrentis simplex Hall	..	x
Zaphrentis sp.	x	x
HYDROZOA		
Stromatopora granulata Nicholson	..	x
Stromatopora nodulata Nicholson	..	x
Stromatopora ponderosa Nicholson	x	..
Syringostroma densa Nicholson	x	..
CRINOIDEA.		
Dolatocrinus canadensis (?) Whiteaves	..	x
Dolatocrinus sp.	..	x
Genneaocrinus sp.	..	x
Hexacrinus leai (?) (Lyon)	..	x
Megistocrinus spinulosus Lyon	..	x
BLASTOIDEA.		
*Nucleocrinus verneuili (Troost)	x	..
BRYOZOA.		
Cystodictya gilberti (Meek)	x	x
Cystodictya incisurata (Hall)	..	x
Fenestella arkonensis Whiteaves	..	x
Fenestella emaciata (?) Hall	..	x
Fenestella sp.	..	x
Fenestrapora biperforata (?) Hall	..	x
Fistulipora sp.	..	x
Lichenalia sp.	..	x
Monotrypa tenuis (Hall)	x	..
Monotrypa sp.	..	x
Orthopora bipinulata (?) Hall	..	x
Reteporina rhombifera (Hall)	..	x
Reteporina striata (?) (Hall)	..	x
Stictoporina plumea (Hall and Simpson)	..	x
Streblotrypa hamiltonensis Nicholson	..	x
Trematoporella sp.	..	x

*Not collected by writer.

BRACHIOPODA.

	Columbus.	Traverse.
Ambocœlia umbonata (Conrad)	..	x
Amphigenia elongata (Vanuxem)	x	..
Athyris spiriferoides (Eaton)	..	x
Athyris vittata Hall	..	x
Athyris vittata indianaensis n. var	x	..
Atrypa reticularis (Linnæus)	x	x
Atrypa spinosa Hall	x	x
Camarotœchia billingsi Hall	x	..
Camarotœchia horsfordi Hall	..	x
Camarotœchia sp.	..	x
Centronella ovata Hall	..	x
Chonetes arcuatus Hall	x	..
Chonetes coronatus (Conrad)	..	x
Chonetes deflectus Hall	..	x
Chonetes hemisphericus Hall	x	..
Chonetes lepidus Hall	..	x
Chonetes mucronatus Hall	x	x
Chonetes scitulus Hall	..	x
Chonetes vicinus (Castelnau)	..	x
Chonetes sp.	x	x
Crania crenistriata Hall	..	x
Crania sp.	..	x
Cryptonella lens Hall	x	x
Cryptonella planirostris Hall	..	x
Cyrtina hamiltonensis Hall	x	x
Cyrtina umbonata alpinensis Hall	?	x
Cyrtina sp.	..	x
Dalmanella lepida (?) Hall	..	x
Delthyris consobrina (d'Orbigny)	..	x
Eunella lincklæni Hall	x	x
Gypidula sp.	..	x
Leiorhynchus kelloggi Hall	..	x
Leiorhynchus laura (Billings)	..	x
Lingula ligea Hall	..	x
Nucleospira concinna Hall	x	x
Orthothetes pandora (Billings)	x	..
Orthothetes sp.	..	x
Pentamerella arata (Conrad)	x	..
Pholidops patina Hall and Clarke	x	..
Pholidostrophia iowaensis (Owen)	x	x
Productella spinulicosta Hall	x	x
Rhipidomella cyclas Hall	x	x
Rhipidomella penelope (?) Hall	..	x
Rhipidomella vanuxemi Hall	x	x
Schizophoria propinque Hall	x	..
Schizophoria striatula (Schlotheim)	..	x
Spirifer acuminatus (Conrad)	x	..
Spirifer audaculus (Conrad)	..	x
Spirifer audaculus macronotus Hall	..	x
Spirifer gregarius Clapp	x	..
Spirifer grieri (?) Hall	x	..
Spirifer lucasensis n. sp	..	x

	Columbus.	Traverse.
Spirifer macrus Hall	?	x
Spirifer manni Hall	x	..
Spirifer pennatus (Atwater)	..	x
Spirifer segmentum Hall	x	..
Spirifer varicosus Hall	x	..
Spirifer venustus Hall	..	x
Spirifer sp.	x	x
Stropheodonta concava Hall	..	x
Stropheodonta demissa (Conrad)	x	x
Stropheodonta hemispherica Hall	x	x
Stropheodonta inæquiradiata Hall	x	..
Stropheodonta perplana (Conrad)	x	x
Strophonella ampla Hall	x	..
Tropidoleptus carinatus (Conrad)	..	x

PELECYPODA.

Actinopteria boydi (Conrad)	x	x
Actinopteria descussata Hall	..	x
Aviculopecten sp.	x	x
Conocardium cuneus (Conrad)	x	x
Glyptodesma erectum (Conrad)	..	x
Glyptodesma occidentale Hall	x	..
Leiopteria dekayi (?) Hall	..	x
Limopteria macroptera (Conrad)	..	x
Limopteria pauperata Hall	x	..
Paracyclas elliptica Hall	x	..
Modimorpha concentrica (Conrad)	x	..
*Panenka alternata Hall	x	..
Pterinea flabellum (Conrad)	x	x
Schizodus sp.	x	..

GASTROPODA.

Bellerophon cf. pelops Hall	..	x
Callonema cf. bellatulum (Hall)	..	x
Callonema lichas (Hall)	x	..
Cyclonema liratum Hall	..	x
*Euomphalus decewi Billings	x	..
*Isonema humile Meek	x	..
Loxonema hamiltoniæ Hall	..	x
Loxonema robustum (?) Hall	x	..
Loxonema sp.	..	x
Murchisonia desiderata Hall	x	..
Murchisonia cf. maia Hall	..	x
Platyceras carinatum Hall	x	..
Platyceras dumosum Conrad	x	..
Platyceras erectum (Hall)	..	x
Platyceras sp.	x	x
Platystoma lineatum Conrad	..	x
Pleurotomaria arata Hall	x	..
Pleurotomaria lucina Hall	x	..

*Not collected by writer.

	Columbus.	Traverse.
Pleurotomaria sulcomarginata Conrad	..	x
Pleurotomaria sp.	..	x
Trochonema meekanum Miller	x	..

PTEROPODA.

Coleolus crenatocinctus Hall	x	..
Coleolus tenuicinctus (?) Hall	..	x
Tentaculites bellulus Hall	..	x
Tentaculites scalariformis Hall	x	..

CEPHALOPODA.

Gomphoceras pingue (?) Hall	..	x
Goniatites sp.	..	x
Gyroceras sp.	x	..
Orthoceras arkonense Whiteaves	..	x
Orthoceras constrictum (?) Vanuxem	..	x
Orthoceras cf. eriense Hall	..	x
Orthoceras nuntium Hall	..	x
*Orthoceras ohioense Hall	x	..
Orthoceras sp.	x	..

CRUSTACEÆ.

Bythocypris indianensis (?) Ulrich	..	x
Bythocypris cf. punctatus Ulrich	..	x
Phacops cristata Hall	x	..
Phacops rana (Green)	..	x
Phacops sp.	..	x
Proetus crassimarginatus Hall	..	x
Proetus macrocephalus Hall	..	x
Proetus planimarginatus Meek	x	..
*Proetus rowii (Green)	x	..

VERTEBRATA.

PISCES.

Dipterus eastmani n. sp	x	..

DISCUSSION OF THE COLUMBUS FAUNA.

The fauna of the Columbus limestone in the above table is essentially the same as in central Ohio. Only one and possibly two species were obtained in this northwestern region which were not found to the east of the anticline. In the Wabash area of Indiana, where the Onondaga phase ranges from zero to about six feet, 42 per cent. of the species of Brachiopoda, Mollusca, and Crustaceæ given above have been identified,[1] while the scarcity of the Corals is a striking feature. In the quar-

*Not collected by writer.

[1]Kindle, E. M., 25th Ann. Rept. of the *Ind. Dept. Geol. and Nat. Res.*, 1900, pp. 565-569.

ries at Whitehouse, Ohio, and at Scott's Ford on the Auglaize River, the Columbus limestone grades into the overlying Traverse without a break. The sudden appearance of *Chonotes coronatus* associated with *Tropidoleptus carinatus* is the most marked feature of the transition. The dividing line between the two formations has, however, been drawn a little lower to include a zone containing a great abundance of *Cyrtina umbonata alpinensis*. There is thus not the slightest indication of the Marcellus, either faunally or in the character of the sediments, since distinctive Hamilton forms appear in the pure crystalline gray limestone identical with that of the Columbus.

DISCUSSION OF THE TRAVERSE FAUNA.

A study of the Traverse fauna shows a relatively greater importance of the Corals than occurred in the Hamilton of the central strip. At one horizon near the middle of the formation there is a decided Coral bed; and again just above the zone containing *Chonetes coronatus* and *Tropidoleptus carinatus* there is another thin Coral bed in which the abundant species are *Acervularia davidsoni* and *Favosites hemisphericus*. In this it is almost the exact counterpart of the fauna in the Grand Traverse region of Michigan.[1] To make the similarity more striking, there are a few Stromatoporoids occurring in the layers just below the *Tropidoleptus* zone. The central part of Ohio shows no such importance of the Corals in the Hamilton, and the entire absence of some of the more characteristic species, such as *Acervularia davidsoni*, *Zaphrentis simplex*, *Favosites nitellus*, etc. Among the Brachiopods the differences are not so apparent, and yet they are important, especially when considered in connection with the horizons at which certain species occur. In the Hamilton of central Ohio *Chonetes coronatus* is an exceedingly rare fossil, while *Tropidoleptus carinatus* was not collected at all, although it has been reported from the upper part of the Olentangy shale. As mentioned above, these two species are the most conspicuous fossils of an important zone near the base of the formation. Both species have a wide geographical distribution and a considerable vertical range, but neither of them found entrance into the Ohio region until Hamilton time, so they are still diagnostic for this horizon. It should be noted that neither of these species are found in the Interior Continental or in the Western Continental area. *Chonetes coronatus* is rather doubtfully reported from Milwaukee,[2] and both are found in Illinois and Indiana. The *Athyris vittata* is not the variety found at the Falls of the Ohio and in central Ohio, but is identical with the form occurring at Milwaukee. *Cyrtina umbonata alpinensis*, which has not been found in the central part

[1] Winchell, Alexander, Rept. on the Lower Penn. of Mich., 1866, pp. 38-59, and appendix, pp. 83-97.

[2] Whitfield, R. P., *Geol. Wis.*, Vol. IV, 1882, pp. 327, 328.

of the state, but is typical at Alpena, Michigan, is an abundant species. *Leiorhynchus kelloggi* is a common fossil in the deposits of this region, as also at Sandusky and at Milwaukee, but not even the genus is known in the Interior Continental area. The Mollusca are essentially the same as in the central strip, and are not very different from this portion of the fauna occurring at Milwaukee. The fauna of the Grand Traverse region[1] of Michigan is a similar association of species, while over 40 per cent. of the northwestern Ohio Hamilton fauna occurs at Thedford, Ontario.[2] Nearly 53 per cent. of the Traverse fossils in this table were also identified in the Hamilton of the central Ohio region, but many of them are rare, and others, such as *Spirifer pennatus*, have been found only in the upper part of the Olentangy shale. The Hamilton fauna of Indiana and Illinois is almost the same. It differs from that of northwestern Ohio, principally in the unimportance of its Corals and, among these, in the absence of diagnostic forms; the scarcity of Crinoids; and in the absence of *Cyrtina umbonata alpinensis*, *Leiorhynchus kelloggi*, *Athyris vittata*, etc., which are among the abundant Brachiopods of the Ohio region. In other words, the regions in question contain the essential constituents of the Hamilton fauna, but show a marked tendency to provincialism.

In the Wabash area of Indiana, which lies in the path of the supposed connection between the Michigan and the Indiana basins, the Hamilton is represented by about 14 feet of impure brown limestone, sometimes in part a true sandstone. The entire fauna given[3] for this deposit is nine species, of which only three, *Spirifer pennatus*, *Atrypa reticularis*, and *Cyrtina hamiltonensis*, are common to the northwestern Ohio Hamilton. All of these have a wide geographic distribution, while only the one, *Spirifer pennatus*, is a diagnostic Hamilton form.

LAND BARRIERS.

Exclusive of the local domings of the Niagara in northern Indiana, there is a broad anticline extending from Marion and Peru northward into Illinois near Momence.[4] The Devonian limestones are not known to cross this fold, although the Black shales are supposed to do so at Crown Point.[5] In northwestern Ohio the Devonian formations dip towards the center of the Michigan basin at an angle of 1° to 5°. A similar dip, at least for the Trenton, is indicated by well records in northern Indiana,[6] while to the south of this fold or ridge the Devonian dips into the

[1]Grabau, Amadeus, Ann. Rept. for 1901, *Geol. Surv. Mich.*, 1902, pp. 175-210.

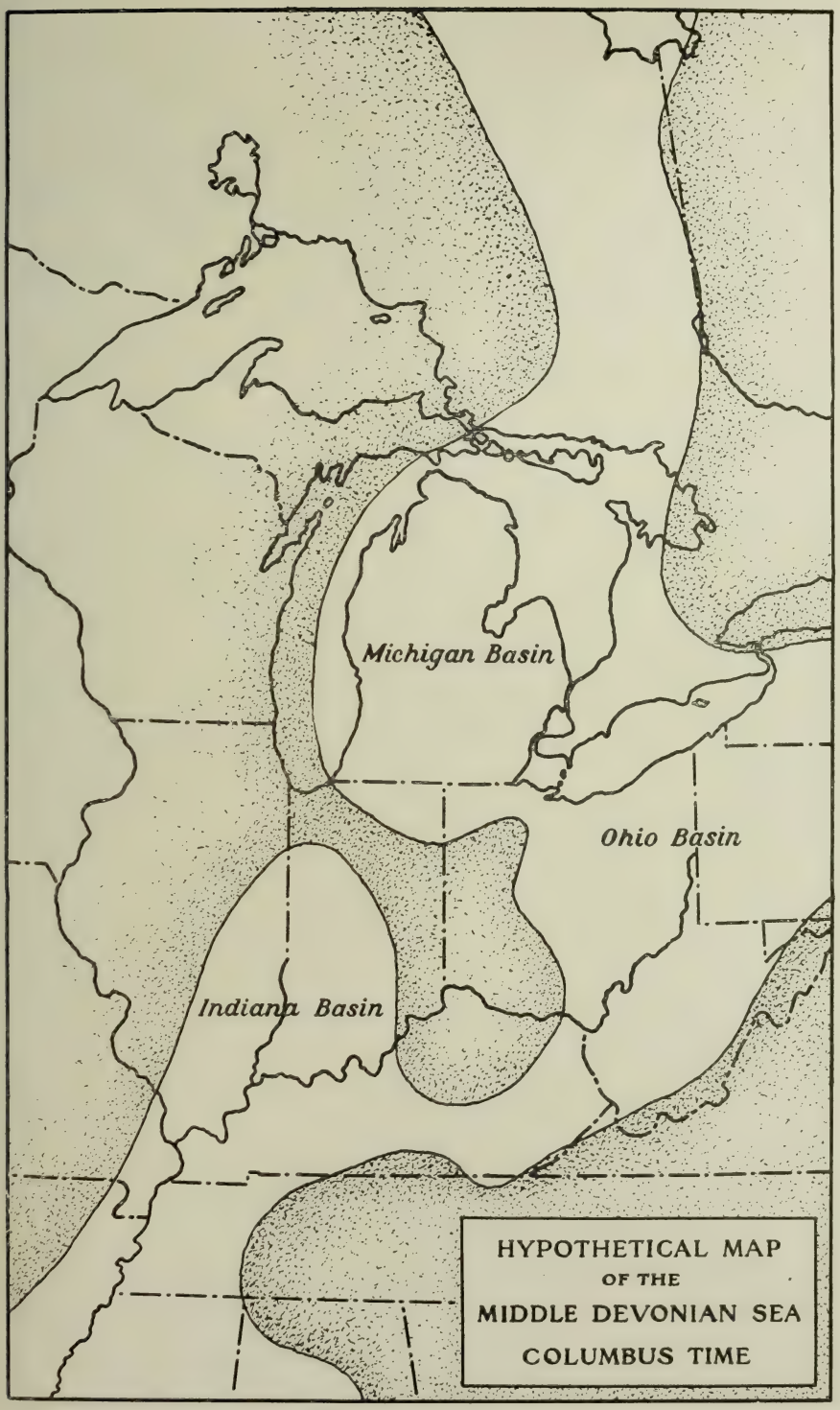
[2]Whiteaves, J. F., Cont. to *Can. Pal.*, Vol. I, pt. 5, 1898, pp. 412-418. Also Grabau, Amadeus, Bull. *Geol. Soc. Am.*, Vol. XIII, 1902, 180-185.

[3]Kindle, E. M., *Op. cit.*, pp. 563, 564.

[4]Gorby, S. S., 15th Ann. Rept. *Geol. Surv. Ind.*, 1886, pp. 228-241. Also Kindle, E. M., *Am. Jour. Sci.*, 4th Ser., Vol. XV., 1903, p. 463.

[5]Leverett, Frank, 17th Ann. Rept., *U. S. Geol. Surv.*, pt. 2, 1896, p. 800.

[6]Phinney, A. J., 11th Ann. Rept. *U. S. Geol. Surv.*, pt. 1, 1891, pp. 648-653, pls. 64-66.


Michigan Basin
Ohio Basin
Indiana Basin
HYPOTHETICAL MAP
OF THE
MIDDLE DEVONIAN SEA
COLUMBUS TIME

Indiana basin.[1] The thin layers of impure sandy brown limestone representing the Onondaga in the Wabash area of Indiana sometimes fail entirely, and the Hamilton rests unconformably on the Niagara with a bed of ferruginous clay between, as at Delphi, while at a nearby locality the Devonian Black shale rests on the Niagara with a similar bed of clay between.[2] At the northernmost outcrop of Devonian in Indiana, Montecello, the Hamilton (?) consists of a "dark gray to almost black arenaceous limestone."[3]

Hence it is certain that there were islands, and probably a land area, connecting the Cincinnati uplift with the land in Illinois during the Middle Devonian time. It is to be noted also that on this same side of the Cincinnati anticline the Hamilton fauna disappears only about 16 miles south of Louisville, Kentucky,[4] while on the east side the blue shales representing the Olentangy are recognized at Waco and thence occasionally northward into Ohio, but fail entirely at Berea[5] and westward, so that the Black shale rests directly on the Onondaga. There is thus no representative of the Hamilton crossing the axis in Kentucky, although the Onondaga does cross[6] and then fails by overlaps of the Olentangy and Ohio shales on the east side from Fleming county,[7] Kentucky, to Pickaway county, Ohio. The Indiana basin may therefore have been entirely separated from direct communication with the Michigan basin during Onondaga, and from both the Michigan and the Ohio basins during Hamilton time. (See Plates XIV and XV).

CONCLUSION.

Along the east side of this land barrier of Onondaga time, the northern element of the fauna spread southward through Ohio and Kentucky westward into Indiana. This migration was principally that of the Corals, Cephalopods, and fishes together with a less distinctive association of Brachiopods, Pelecypods and Gastropods. Over this same route the southern element, consisting of a different association of Brachiopods, Pelecypods and Trilobites, spread northward. These, at least in part, may have been of South American[8] origin, while others had lived in the region of southern Illinois during Oriskany time.

By the beginning of the Hamilton, the Cincinnati land mass became

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[1]Kindle, E. M., 25th Ann. Rept. *Ind. Dept. Geol. and Nat. Res.*, 1900, pp. 562-564.

[2]Kindle, E. M., *Am. Jour. Sci.*, 4th Ser., Vol. XV, 1903, p. 467.

[3]Kindle, E. M., *Op. cit.*, p. 563.

[4]Foerste, A. F., *Geol. Surv. Ky.*, Bull. No. 7, 1906, p. 15.

[5]Foerste, A. F., *Op. cit.*, pp. 104, 105.

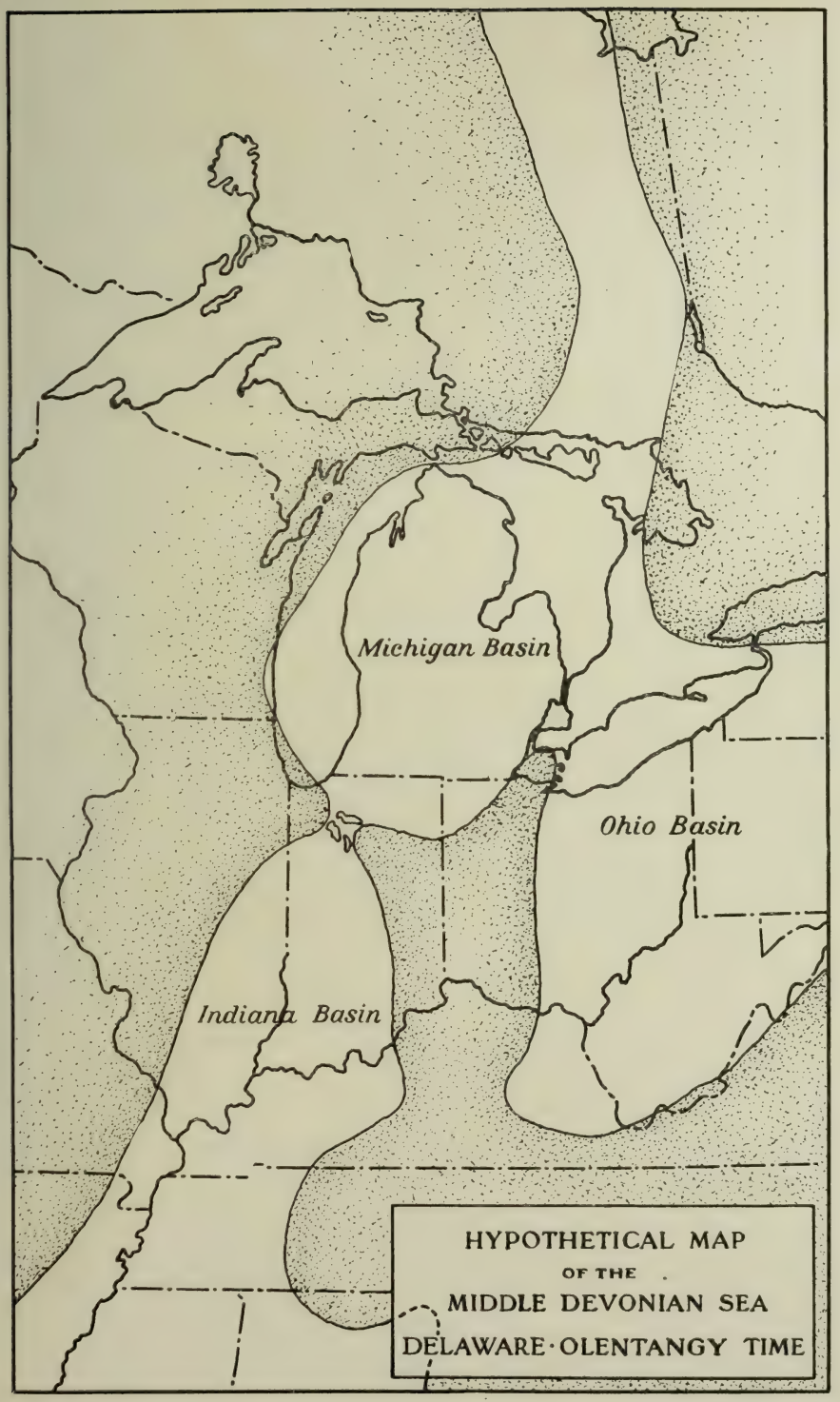
[6]Foerste, A. F., *Op. cit.*, p. 16.

[7]Linney, W. M., *Geol. Surv. Ky.*, Rept. on the Geol. of Fleming Co., 1886, pp. 74-76.

[8]For a complete list of the South American Devonian faunas and their relationships, see Thomas, Ivor, *Zeitschr. d. deutsch. Geol. Ges.*, Vol. LVII, 1905, pp. 233-290.

connected to the south with the land of the Appalachian region; and the connection, in northwestern Indiana, with the land lying to the west, if such connection existed during Onondaga time, was probably broken temporarily, and through this gap immigrants from South America found their way into the Michigan basin. This direct connection was probably of short duration, as some of the characteristic Michigan basin species apparently did not migrate south through it.

Finally at the close of the Hamilton the Interior Continental sea probably succeeded in establishing communication with the Michigan basin by way of Milwaukee, and a mingling of the eastern and western faunas took place, but the conditions which gave rise to the Black shale had set in, and Ohio furnishes no certain evidence of this event.


Michigan Basin
Ohio Basin
Indiana Basin
HYPOTHETICAL MAP
OF THE
MIDDLE DEVONIAN SEA
DELAWARE·OLENTANGY TIME

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CHAPTER IV.

INTRODUCTION.

Specimens, which were not capable of specific identification, have been given generic names, where possible, and referred to their proper horizons. This, however, must be given a generous interpretation. If, for instance, *Spirifer sp.* is mentioned as occurring in horizons 1, 2, 3, etc., it does not necessarily mean that the same species occurs in these three horizons, but that an undetermined *Spirifer* has been found in each of the beds thus designated.

The following notes include such observations as have been made during a study of the fossils collected from the Middle Devonian. A certain few specimens have remained unidentified with any published forms. These have been figured and described as new species. Fragments of others have been found which seem also to be new, and hence it is rather certain that the fauna of these formations is still but imperfectly known.

RHIZOPODA.

There is but one *Rhizopoda*, a Foramenifera, known to occur in these formations, and that is *Calcisphæra robusta*[1] of the Columbus limestone. This little fossil has been found from Columbus northward to the lake and less commonly in northwestern Ohio. At Marblehead and on Kelley's Island it occurs in great numbers, often making up a large part of the rock.

SPONGIA.

So far as known, only one species of Spongia, *Receptaculites devonicus* has ever been collected from these formations, and it is rare.

ANTHOZOA.

Corals are abundant in the Columbus limestone and not rare in the Hamilton formations of Ohio. Some of these are probably new, but no good specimens have been collected which are evidently of undescribed species.

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[1]*Calcisphæra robusta* Williamson. *Phil., Trans. Roy. Soc. London*, Vol. CLXXI, 1880, p. 523, pl. 20, fig. 81.

This little fossil has been referred to by several writers, chief among whom were Dana and Seward, as the seed of a *Chara*. Williamson, however, was inclined to consider it as a Foramenifera and this is the opinion held by the writer, although the evidence is probably not sufficient to demonstrate either view. The type specimen was taken from Kelley's Island, Ohio.

HYDROZOA.

Dictyonema is a rare fossil, but *Stromatopora* is abundant in the Columbus limestone, and occasionally is found in the Delaware and Traverse formations.

CRINOIDEA.

Crinoid stems and segments are abundant throughout the fossiliferous portions of these formations. This is especially the case with the Columbus limestone, which is sometimes nothing more than a mass of such remains. The calices, however, are rare and good specimens exceptional.

BLASTOIDEA.

Of the three Blastoids, *Nucleocrinus verneuili* (Troost) is a common fossil in the upper part of the Columbus limestone, while the others are rare. Doubtless some of the stems and segments usually called Crinoid segments are really Blastoid fragments.

BRYOZOA.

Bryozoans are more or less abundant in the Middle Devonian formations of Ohio. Many of them, however, are not well preserved, and hence are beyond identification to the eye not especially trained for the detection of their specific differences. For this reason the lists of species, in the preceding chapters, are relatively too poor in this class of fossils.

BRACHIOPODA.

Athyris vittata indianaensis n. var.

Athyris vittata Hall. Pal. N. Y. Vol. IV, 1867, pl. XLVI, figs. 1-4,

This variety is quite common in the Columbus limestone. It differs too much, however, from the form, which is the type of the species, found at Iowa City, Iowa (13th Rept. N. Y. State Cab. Na. Hist., 1860, p. 89), to be included under the same specific name. It has a much more pronounced fold and sinus, and is less lamellose than specimens from the original locality. Neither does it seem justifiable to identify this species with *A. fultonensis* (Trans. St. Louis Acad. Sci. Vol. I, 1860, p. 650.) This last named species, as found at Iowa City, the type locality, is distinct. It is a much narrower elongate form with the fold and sinus but poorly defined. The above variety name is used to distinguish the Columbus form from that occurring in the Traverse.

Horizon and locality.—Common throughout the Columbus limestone at Columbus, Marion, Sandusky, etc.

Spirifer lucasensis n. sp.

Plate XXIII, figs. 1-5.

Shell more or less gibbous, becoming subglobose in the older speci-

mens. Hinge line equal to or greater than the greatest width of the shell. Cardinal extremities usually not produced. Surface plicated.

The pedicle valve becomes much the more gibbous in the mature shell, although in the young individuals the difference is slight. The curve of the median line of the valve decreases rapidly from beak to front. Beak incurved and approaching that of the brachial valve in older specimens. Area of moderate size and decreasing to the extremities of the hinge line. Mesial sinus well defined, moderately deep, flattened, and with a single angular plication in the center. The front of the sinus is usually much produced.

The branchial valve is convex, with a small incurved beak. Area small and distinguishable only in the central part of the hinge line. Mesial fold well defined and deeply marked by a central depression, or furrow, extending almost or quite to the beak.

Surface marked, on each side of the fold and sinus, by six to ten simple strong angular plications of which the one on either side of the sinus is more pronounced. In well preserved specimens the surface is further marked by lamellose zigzag, imbricating lines of growth.

An average specimen measures .5 inch in thickness, .8 inch in length and .8 inch in width.

This species resembles somewhat *Sp. gregarius*, and possibly Hall's figures 9 and 10, plate XXVIII in Volume IV, Paleontology of New York, of species from the cherts of southern Indiana may be of the same species. It also has a slight resemblance to Hall's *Sp. bimesialis*, and again it resembles *Delthyris consobrina*, but in each case its differences are sufficiently great to separate it easily from them.

Horizon and locality.—This species is quite abundant in the lower part of the Traverse formation, in the quarry of the Whitehouse Stone Company at Whitehouse, Lucas county, Ohio.

Spirifer pennatus (Atwater.)

Terebratula pennata Atwater. Am. Jour. Sci. Vol. II, 1820, p. 244, pl. I, figs. 2, 3.

The variety of *Spirifer pennatus*, so common in the shales along Eighteen Mile Creek, New York, is quite abundant in the soft shales of the Olentangy formation south of Sandusky. Quite a different form occurs in the shaly part of the Traverse formation at Junction, Ohio. Some of these specimens resemble *Spirifer pennatus thedfordensis* (Grabau, Bull. Geol. Soc. Am. Vol. XIII, 1902, pp. 171-176), and probably should be referred to that variety. A few were found, however, which have much coarser imbricating lines of growth, and all have an area which must be described as high, considering the species of which it is a variety. Probably this should be considered as a new variety, and if so the name *Spirifer pennatus auglaizensis* would certainly be appropriate.

Horizon and locality.—In the soft shales of the Traverse formation, Hager quarry, Junction, Ohio.

Spirifer venustus Hall.

——— ——— Hall: 13th Rept. N. Y. State Cab. Nat. Hist., 1860, p. 82.

Spirifer divaricatus Hall: Pal. N. Y. Vol. IV, 1867, pp. 213, 214, pl. XXXII, figs. 4-8.

This species, which Hall himself repudiated, is doubtless distinct. It differs from the real *Spirifer divaricatus* in its more rounded outline, the much greater number of rounded bifurcating plications and the less angular fold and sinus. It has reached a later stage in the developmental history of the genus, and hence the name is here retained as the specific designation of the Hamilton forms. *Sp. divaricatus* is to be found in the Columbus (Onondaga) limestone throughout the state, but it has never been found to grade into *Sp. venustus*.

Horizon and locality.—Traverse formation, Ten Mile Creek, Silica, Ohio.

PELECYPODA.

Palæoneilo (?) sanduskiensis n. sp.

Pl. XXIII, figs. 7, 8.

Shell large and sub-quadrate, length nearly twice the width; posterior extermity obliquely truncated and somewhat pointed; anterior end rounded. Hinge line slightly arched; basal margin nearly straight towards the posterior end, forming an angle of nearly 45° with the cardinal line, and then sweeping around in a broad arch, over the last two-thirds of its length, to the hinge line.

Valves convex with the greatest gibbosity in front of the small beaks, and which latter are somewhat in front of the middle of the hinge line. The posterior portion of the shell decreases in convexity gradually until a little more than half way to the end, where there is a sudden decrease in the same. The valves were probably thin, as shown by the preservation of surface characters and of strong adductor muscular impressions.

Surface marked by well defined concentric lines of growth.

Horizon and locality.—Lower part of the Delaware limestone, Wagner quarry No. 1, Sandusky, Ohio.

GASTROPODA.

Bellerophon hyalina Hall.

Pl. XXIV, figs. 3, 4.

——————— Hall: Pal. N. Y. Vol. V, pt. II, 1879, p. 99, pl. XXVI, fig. 4.

This species is quite common in the chert beds of the Columbus limestone, and might have been described as a new species were it not

for a provisional statement which Hall makes in his description. He says that "although no dorsal band has been observed, it is possible that such a feature may exist in better preserved specimens."

The specimens collected show a well defined slit band which is limited on either side by a nearly plain concave surface and ornamented in the central part by the same cancellated striæ characteristic of the remainder of the shell. Of the revolving striæ in the slit band there are usually four or five.

The type of this species was collected in the cherty layers of the Onondaga limestone near Jamesville, Onondaga county, N. Y., where the "association of species is, in many respects, extremely similar to that of the cherty beds at Dublin, Ohio."

Horizon and locality.—The chert zone of the Columbus limestone at Dublin, Eversole Run, etc.

Macrochilina hebe Hall.

——————— Hall: Pal. N. Y., Vol. V, pt. II, 1879, p. 32, pl. XII, figs. 4–7.

All of those specimens collected and which have been referred to this species are small (as is frequently the case with a large part of the fauna of the chert zone) and possibly the spire is a little more elevated than in the type figures, but otherwise they agree very well with Hall's figures and descriptions.

Horizon and locality.—Chert zone of the Columbus limestone, Eversole Run, Ohio.

Murchisonia eversolensis n. sp.

Pl. XXIII, fig. 13.

Shell elongate turriteliform; spire angle 30°. The portion preserved lacks perhaps three or four whorls from the apex, is two-fifths of an inch long at a place where the basal measurement is one-quarter inch, and has three rather closely coiled laterally flattened volutions.

The surface is marked by a plain spiral band and by a few rather indistinct concentric striæ which swing backward towards the band and then forward to the columella. Suture line distinct and well up towards the band.

Horizon and locality.—The chert zone of the Columbus limestone, Eversole Run.

Murchisonia intermedia n. sp.

Pl. XXIII, fig. 9.

Shell moderately elongate, sub-fusiform; angle of spire about 48°; volutions rounded and, in the specimen figured, five in number.

Surface marked by strong concentric striæ, bending back gently to the slit band which they show no evidence of crossing. The band is limited above and below by very pronounced sharp carina, and the center of the band marked by a series of papillæ or knot-like elevations

caused by the meeting of the growth lines or striæ, which are more numerous than on either side of the band.

This species may be compared with both *M. leda* and *M. maia*, being somewhat intermediate between the two.

Horizon and locality.—Rare in the chert zone of the Columbus limestone, Eversole Run, Ohio.

Murchisonia quadricarinata n. sp.

Pl. XXIV, figs. 10, 11.

Shell with a very high spire. Spire angle about 20°. Seven to ten or more rather closely coiled volutions which increase in size gradually from apex to base. Aperture probably sub-quadrate in outline.

Surface marked with four carina which simulate a revolving slit band, but probably only the inner two represent that feature. As a further surface ornamentation there are numerous concentric striæ which start at the suture, sweep over a pseudo-carina and are lost near the upper carina. The suture usually covers the lower carina.

Horizon and locality.—Chert zone of the Columbus limestone at Dublin and Eversole Run, Ohio.

Platyceras blatchleyi Kindle.

Pl. XXIII, figs. 11, 12.

——————— Kindle: 25th Ann. Rept. Dept. Geol. and Nat. Res. of Ind. 1900, p. 733, pl. XVII, fig. 6.

The specimen here figured probably belongs to this species, but it shows some important variations. The shell is more erect and its apex closely enrolled for more than a complete volution. Along the compressed angular dorsum there are probably fewer spines (only three preserved) and these curve off rapidly to the left of the shell instead of being directed straight backward. The right side is considerably expanded while the left is nearly flat. And finally, the surface is marked by wavy concentric lines of growth which suggest that the margin was probably crenate.

Horizon and locality.—Upper part (Zone H) of the Columbus limestone along Indian Run at Dublin, Ohio.

Platystoma subglobosa n. sp.

Pl. XXIII, fig. 6.

Shell subglobose in shape; spire but slightly elevated; angle of spire 112°; six volutions, of which four are exceedingly small, are shown. The body whorl is much expanded and makes up more than five-sixths of the entire shell. Suture shallow. Aperture circular; the outer lip thin, the inner reflexed over the umbilicus, forming a callosity.

Surface marked by rather indistinct striæ parallel to the outer edge of the lip; occasionally these striæ are crowded together and more pronounced.

Horizon and locality.—The chert zone of the Columbus limestone Eversole Run.

Pleurotomaria cancellata n. sp.

Pl. XXIV, figs. 1, 2.

Shell somewhat depressed; spire angle 92° in the specimens figured; from four to five depressed rounded volutions. Aperture subquadrate and with no true columella; umbilicus covered by the callosity of the inner lip.

Surface marked by strong concentric and revolving striæ which form a lattice-like pattern, best observed on the lower part of the body whorl. There is also a well defined slit band and two prominent carina present on either side of the band with its minor limiting carina. From the suture to the upper carina the concentric striæ are strong and swinging backward are crossed by only a few revolving striæ, but these sometimes have the appearance of secondary carina and may even be reduced to one. After crossing the carina the concentric striæ are much less prominent, but three or four times as numerous. Crossing the slit band with an arc-like course (concave foreward) and no median carina, the concentric striæ swing forward to a sharp carina similar to that above the band, lose two-thirds or more of their number and converge to the umbilicus. On this lower part of the body whorl, the concentric striæ increase by implantation.

Compare this species with *P.* (*Bembexia*) *sulcomarginata* Hall.

Horizon and locality.—Rather common in the chert zone of the Columbus limestone, Eversole Run.

Pleurotomaria dublinensis n. sp.

Pl. XXIV, figs. 7, 8, 9.

Shell conical; angle of spire about 47° in the specimen figured. Four rather rounded volutions preserved and probably three missing. Aperture somewhat quadrate but inclined to be rounded.

Surface marked by concentric striæ which appear to be simple radiate from the well defined suture and then curve slightly backward to the slit band. Below the band the striae make but a slight forward curve and then converge to the umbilicus. The slit band is sharply defined on either side by a carina and there seems to be no markings within the band.

All specimens of this species collected were exceedingly small. The larger specimen figured is about one-eighth of an inch in length.

Horizon and locality.—The chert zone of the Columbus limestone at Dublin and also along Eversole Run.

Pleurotomaria hyphantes Meek.

——— ——— Meek: Geol. Surv. Ohio, Vol. I, pt. II, Pal., 1873, p. 227: pl. XX, fig. 6.

Meek figures and describes this species referring it doubtfully to *P. lucina.* He concludes his description, by saying that "should it prove to be distinct, however, it might be designated as *P. hyphantes*, in allusion to its beautiful textile style of sculpturing." The specimens of this species collected are excellent and are certainly not *P. lucina.* Its spire is higher, the inner lip of the aperture is more extended, and the band, as well as the general surface of the shell, is more highly ornamental.

Horizon and locality.—The chert zone of the Columbus limestone. Dublin, Deer Run, Eversole Run, etc. Ohio.

Pleurotomaria sciotoensis n. sp.

Pl. XXIV, figs. 5, 6.

Shell higher than wide, conical in outline; spire angle 71°; five volutions preserved, the last one considerably expanded.

Surface marked by strong concentric striæ or ridges which often bifurcate on the lower side of the body whorl. The surface is further marked by a sharply carinated revolving band, limited above and below by less conspicuous marginal carina; also there is a sharp carina midway between the band and the suture line while below the band there is a similar sharp carina at about the same distance. The concentric striæ start straight out from the suture line and then swing backward, bending forward again just before reaching the first carina. They then swing backward rapidly and sometimes bifucate and become less conspicuous as they reach the slit band. The concentric markings on the band do not definitely connect with those outside and may be either of the same number or more numerous. Below the band the striæ swing forward towards the lower carina and do not show the same tendency to bifurcate; after passing the carina they converge towards the umbilicus and many of them unite before reaching it. Umbilicus closed by a callosity.

This species should be compared with Hall's *P. triplex* of the Hamilton.

Horizon and locality.—The chert zone of the Columbus limestone, Eversole Run, Delaware county, Ohio.

Straparollus corrugatus n. sp.

Pl. XXIII, fig. 10.

Shell turbinate with spire depressed at the apex; spire angle about 90°. Five rounded whorls, the lower of which is somewhat depressed. Aperture circular; umbilicus large.

Surface marked by rather strong and medium coarse transverse or concentric striæ which suggest corrugations of the shell.

Horizon and locality.—The chert zone of the Columbus limestone, Eversole Run.

CEPHALOPODA.

Cyrtoceras metula (?) Hall.

——— ——— Hall: Pal. N. Y. Vol. V, pt. II, 1879, pls. XLVII, figs. 1, 2, and CXI, fig. II, p. 360.

The surface of the test of this specimen is marked by fine transverse striæ of growth which curve slightly toward the posterior, dorsally to the siphuncle.

Horizon and locality.—The chert zone of the Columbus limestone, Eversole Run.

Orthoceras ohioensis Hall.

——— ——— Hall: Pal. N. Y. Vol. V, pt. II, 1879, p. 236, pl. XXXV A, figs. 8, 9 and also pl. XXXVI, fig. 4.

The surfaces of most of these specimens are smooth and show no indication of the chambered interior. One specimen, however, is partly exfoliated and shows the interior nicely. Another specimen shows a trace of the original color.

Horizon and locality.—The chert zone of the Columbus limestone, Deer Run, Eversole Run, etc.

CRUSTACEÆ.

Dalmanites.

Upon the advice of Dr. Weller, the sub-genera of *Dalmanites* have been recognized as of full generic rank. They are certainly of sufficient importance to be readily recognized as constituting well defined specific groups and doubtless deserve the rank here given them.

Proetus welleri n. sp.

Pl. XXIV, figs. 12, 13.

Outline of entire body oval, the greatest length being nearly twice the greatest width (1.22 inch long and .64 inch wide.)

Cephalic shield crescent shaped and moderately convex; genal angles produced into spines marked by a few indistinct striæ on the under side. Free cheeks separated from the fixed cheeks by a suture which curves rather abruptly outward from the front of the eye, and then swings towards the median line before cutting the outer margin, making thus a more complete double curve than usual. A well defined glabella moderately convex, short and tapering rapidly to a rounded front, which fails to reach the frontal margin by fully one-third of the length of the cephalon. The glabella is exfoliated and shows the primitive five furrows, although the anterior pair is rather indistinct and transverse while the posterior furrows are directed backward. Occipital lobes large, eyes of medium size and moderately convex.

Thorax of ten segments; the axis narrow, strongly convex and tapering gradually to the pygidium; the pleura rather flat from the axis

to about half the distance to the margin, where they curve abruptly downward.

Pygidium semicircular, not distinctly emarginate; length about two-thirds the width and nearly one-third the entire length of the body. The axis diminishes in convexity rapidly from the point of union with the thorax and terminates bluntly one-tenth of an inch within the margin, Twelve annulations on the axis. Pleura convex and not flattened near the axis, nine divisions may be counted and these become obsolete before reaching the border.

This species is named in honor of Dr. Stuart Weller, in appreciation of his interest in the fauna.

Horizon and locality.—The upper part of the Columbus limestone in the Lake Shore Railroad quarry south of Venice, Ohio.

PISCES.

Dipterus eastmani n. sp.

Pl. XXIV, figs. 14–17.

An upper dental plate which is more or less triangular in outline and rather more convex than usual for the genus. It is chiefly characterized by the appearance of but three major denticulated ridges, in front of which there are at least three other similar but rather inconspicuous ridges. There are from six to eight denticulations preserved on the major denticulated ridges and apparently from three to five on the indistinct minor ridges. The coronal surface is well worn and shows punctations. The anterior end of the plate is somewhat extended beyond the coronal surface and tapers gradually to the front. This latter is probably a remnant of the pterygo-palatine bone.

There is reason to believe that this specimen is fragmentary, but the portion preserved measures 1.6 inch in length, and .8 inch in width It should be compared with *D. uddeni* (N. Y. State Mus. Mem. 10, 1907, p.160, pl.IV, figs. 3, 4), from which it differs in the number of denticulated ridges and in general outline.

This species is named in honor of Dr. Charles R. Eastman, who has contributed so much to our knowledge of the fossil fishes of North America.

Horizon and locality.—This specimen was found in the zone from five to ten feet below the top of the Columbus limestone in the quarry of the Whitehouse Stone Company, at Whitehouse, Ohio.

Note:—The types of the species above described may be found in the Geological Museum of the Ohio State University.

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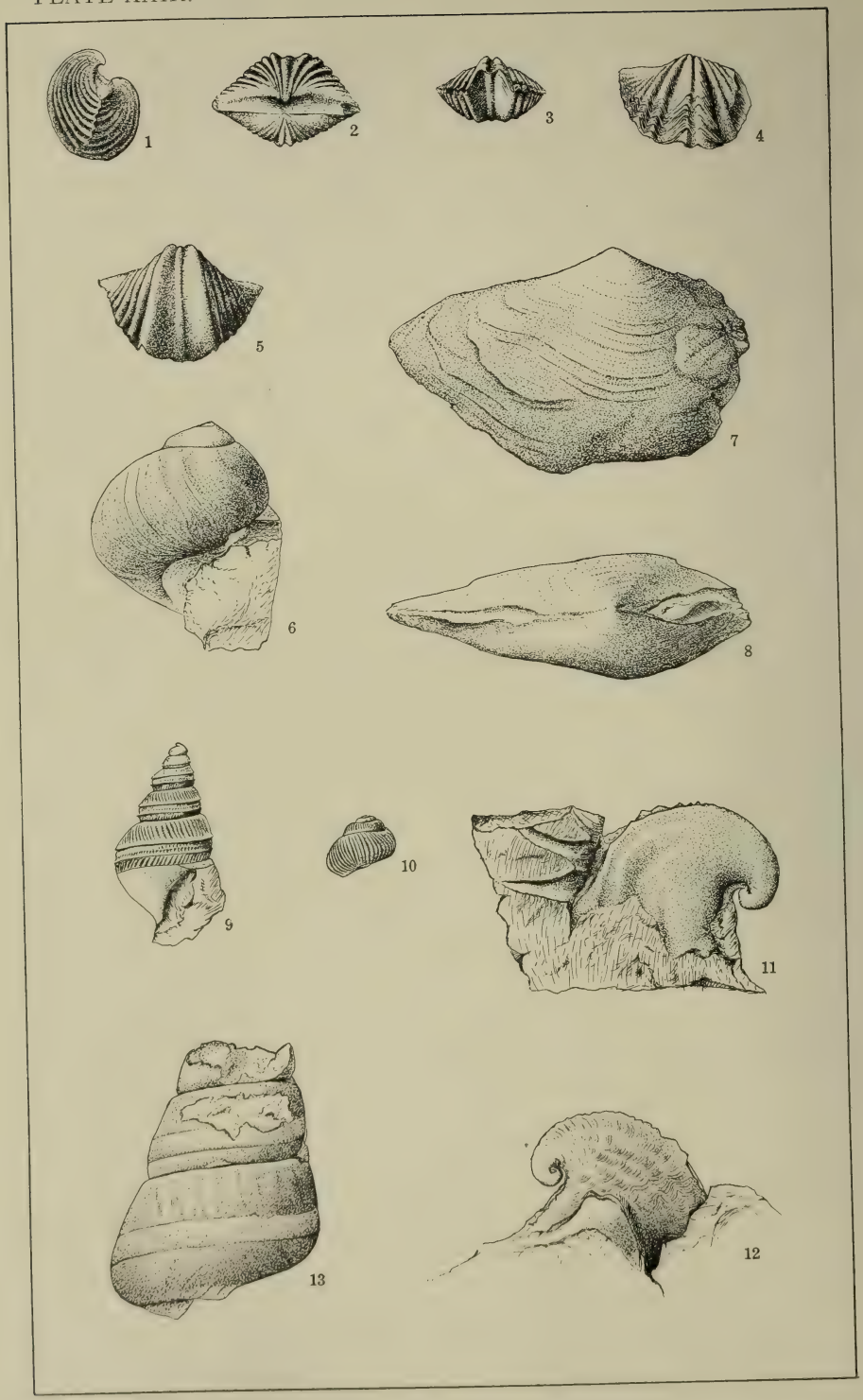
PLATE XXIII.



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*15—S. G.—1,000.

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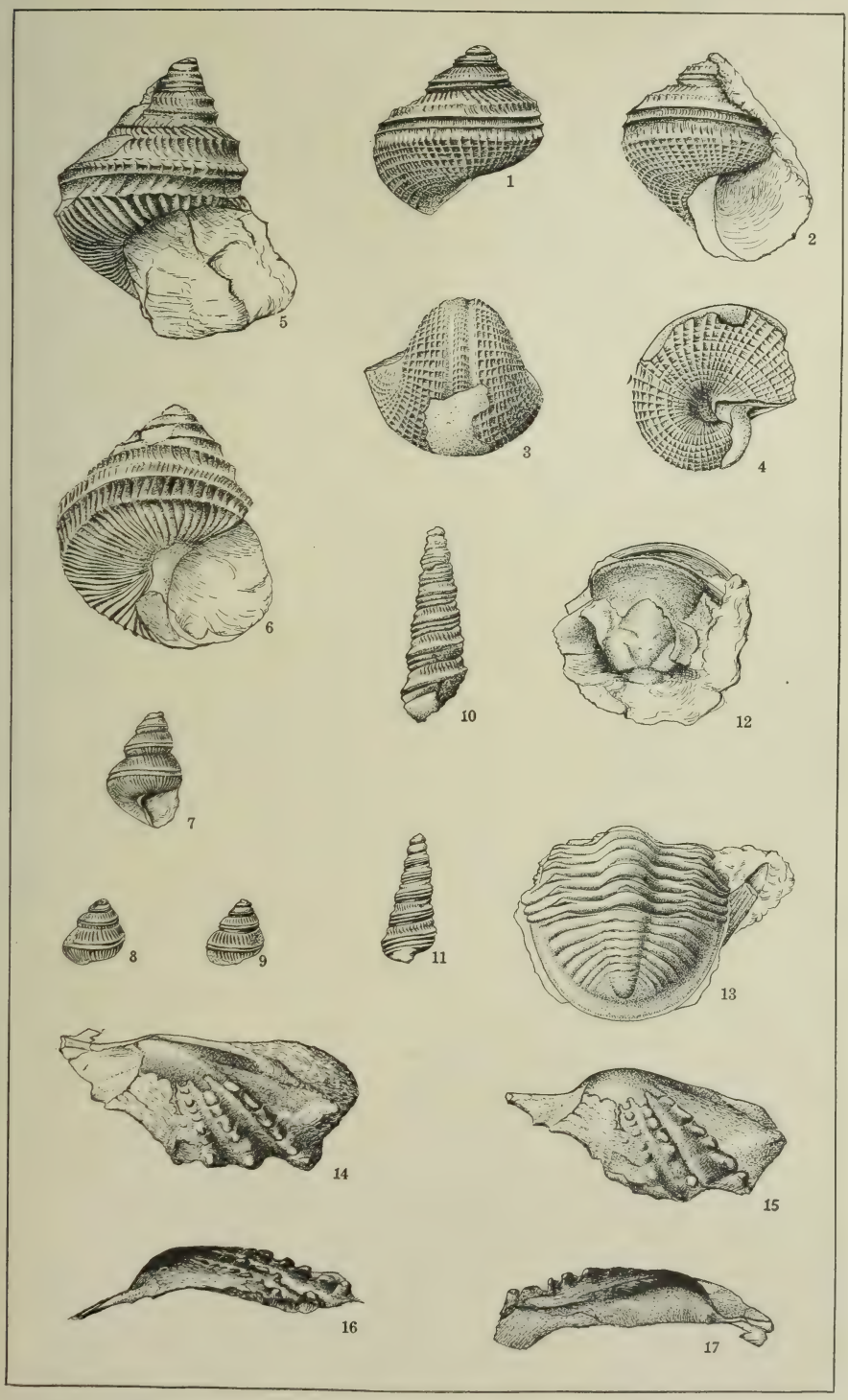

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FOURTH SERIES, BULLETIN 11

THE MANUFACTURE OF ROOFING TILES

By

WOLSEY GARNET WORCESTER

EDWARD ORTON, Jr., Collaborator and Editor

AUGUST, 1910

1—G. B. 11—1,000.

LETTER OF TRANSMITTAL.

Dr. J. A. Bownocker, State Geologist:

Dear Sir—I take pleasure in handing you herewith the first one of a series of Bulletins on the Clays and Clay Products of Ohio. The subject of this bulletin is Roofing Tiles, and has been prepared under my general direction by Mr. Wolsey Garnet Worcester, Instructor in Ceramic Engineering in the Ohio State University, and formerly identified with the Roofing Tile industry as designer, builder and operator of roofing tile factories.

The manufacture of roofing tile is not one of the most extensive of the clay industries, either in Ohio or in the United States. The reason for its treatment in the first of the proposed series of Bulletins on the Clay industries, is that it is the first report to reach completion, out of several which are under preparation. As this report is practically an independent and complete treatise in itself, no adequate reason exists for delaying its appearance until other reports are ready.

It has been the aim in this report and in the others which are to follow on allied topics, to diverge quite widely from the type of reports formerly issued by this and most of the other states, in which the geology of the clay beds, their occurrence and extent, have been the matters of first importance and the technology of the clay industry has been generally lightly touched upon. It is my belief that of the clay beds of Ohio and their occurrence, and quality, enough has been said already by the reports of the Geological Survey to very fairly present this topic to the people of the State. But the utilization of clays of the types found in Ohio is a matter of very much more intricate nature than their geological occurrence, and in this subject no headway can be made to convert the clays into an asset of wealth, except through an understanding of the technological processes of manufacture and the physical and chemical principles on which these processes rest. These reports are therefore directed primarily towards enabling the people of the State to use the clay resources which are available, and are therefore primarily technologic, rather than geologic in character. Mr. Worcester is peculiarly competent to present to the public an article on the manufacture of roofing tiles, on account of his practical experience in this industry, and it is anticipated that the value of his contribution will speedily be recognized when the report reaches the producers and users of clay architectural materials.

Very Respectfully submitted,

Edward Orton Jr., E. M.

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CHAPTER I.

A BRIEF HISTORY OF ROOFING TILE MANUFACTURE AND USE.

General—The origin of roofing tile is shrouded in obscurity. It can, however, be traced back several centuries before Christ. Early in man's career, he doubtless lived in such caves and natural shelters as are found in a mountainous country, but, as he migrated from place to place, it would happen that natural shelters could not always be found. The impulse and suggestion for him to construct temporary caves, or shelters of slabs and pieces of rock, would be a perfectly natural one and doubtless has recurred many times in various places and peoples in the development of the human race. These early homes were no doubt covered with some sort of thatch or stone roofing material; in mountainous countries flat stones of flaggings would naturally be tried. Experience unquestionably soon taught these early home builders the value of a sloped roof over a flat one, in shedding the rains.

According to Morse[1], the antiquity of the sloping roof is hinted at in the finding of cinerary vessels in the form of huts, and, consequently, known as hut-urns. These have been found in Italy, Saxony and other parts of southern Europe. It is believed they were made before the age of iron.

The sloping roof must have preceded the roofing tile by many centuries. At the outset, bark, straw, thatch, rough stones and similar substances were used until better devices were made, which finally culminated in roofing tile of terra-cotta. The oldest known type of clay roofing tiles is, by far, the most common form in use in the world to-day.

Most natural stones crumble, and metals oxidize or rust, but hard burned clay wares are nearly imperishable to the influences of decay. Thus it happens that terra-cotta roofing tiles are often the only surviving relics of a prehistoric structure. The enduring nature of these objects may ultimately enable us to trace the paths followed by the tile-making races in their various migrations.

While the actual beginnings of roofing tiles are not known, it is probable that their use was known very early in Asia Minor, and certainly very early in China. From the high skill of the potters and the great

[1] Morse, E. S. "On the Older Forms of Terra-Cotta Roofing Tiles," Amer. Arch. and Building News [1892] vol. 35, p. 197, vol. 36, pp. 5, 24, 52. This article has been freely used in various parts of this chapter, for which due acknowledgment is hereby rendered.

antiquity of the fictile art in China, and the use of artistic roofing tiles in that country in buildings erected some centuries ago, one might easily be led to believe that it was in China that the use of roofing tile originated.

Graeber, in his memoir "Terra-kotten am Gieson," describes what he believes to be the earliest known terra-cotta roofing tile. These were found in the ruins of the Temple of Hera at Olympia, dating nearly a thousand years before Christ. This ancient tile consisted of two elements, a wide under piece (tegula) slightly curved, and a narrow, semi-cylindrical piece (imbrex) which was placed in an inverted position so as to cover the upturned edges of two adjacent tegulae. While the tiles from the Temple of Hera are probably as old as any authenticated instances elsewhere, it is not to be supposed that the Greeks sprang all at once from the thatched hut of the wild sheep-herder, up to the level indicated by this efficient system of tile roofing. It is known that the beginnings of their other arts, pottery making, metal working, jewelry, sculptures, etc., were imported from older civilizations in Asia Minor, or elsewhere, and that while the genius of the Greeks soon developed all of these arts to a plane never before known in the world, they cannot be credited with their first discovery.

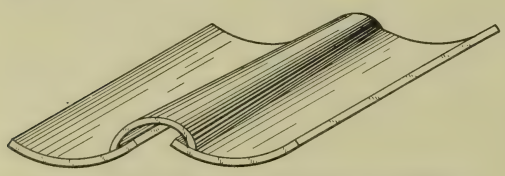


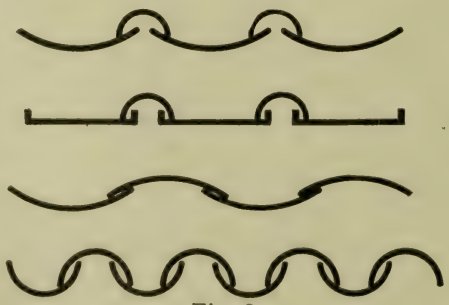
Fig. 1—Tiles from the Temple of Hera.

Among the substances used in the construction of early roofs, worked marble tiles, modeled after the terra-cotta tiles, were made some 650 years before Christ.

Throughout all parts of the old world can be found tiles or the fragments of them, proving to us that the use of tile has been universal there at one period or another.

The outline drawings[1] (Figure 2) represent in a general way the types and varieties of roofing tiles with their age and distribution.

Normal or Asiatic Tile Designs.



The Orient, Ancient Greece and Italy.

China and Italy.

The Orient, Asia and Mediterranean Countries.

Greece, Italy (Ancient and Modern).

Fig. 2

It should be understood that colonies, past and present, usually adhere to the form of roofing tile in use in their parent countries. As

[1] After Morse, On the Older Forms of Terra Cotta Roofing Tile, Amer. Archt. and Building News, (1892), Vol. 35, p. 198.

an illustration,[1] flat tile made in Montgomery County, Pennsylvania. about 1735, can be traced to the old German settlers. At Bethlehem, Pennsylvania, the Moravians were making tile as early as 1740.[2] The pan tile discovered by Dr. C. C. Abbott[3] on Burlington Island, in the Delaware River, on the site of a very old house, said to have been built in 1668 by Peter Jagon, points clearly to the Dutch settler as its author. In California and Mexico, the normal or half round tile used in the missions were made by the early Spanish conquerors.

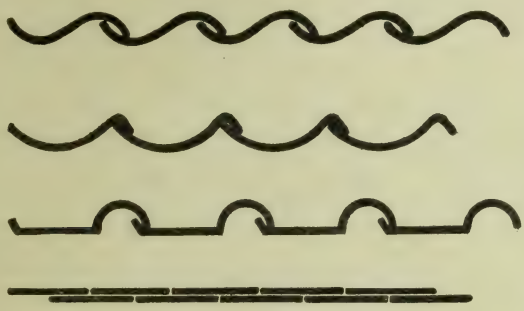


Fig. 2—Continued.

The tiles found in the above described localities are believed to represent the first use of roofing tiles in this country. It is quite possible that some of the first tiles used were brought from home by the colonists from their respective countries.

Ohio—Taking up the history of roofing tile in Ohio, it has been found a problem of less magnitude to trace their development.

On a branch of the Cincinnati Northern Railway, some thirty miles to the northeast of Cincinnati, is found the quaint old village of Germantown, which the records seem to indicate as the site of the first roofing tile manufacture and use in Ohio.

During the year of 1814,[4] Mr. Philip Gunckel laid out the village, and named it after Germantown, a suburb of Philadelphia, which still retains that title. About this time a Mr. John Robinson cast his lot with the early settlers of the little town, and began the manufacture of brick from clay gathered in a nearby field. Wishing to build for himself a home that would outdo those of his pioneer neighbors, Mr. Robinson made clay roofing tiles in quantity sufficient to cover his home and stable. Figure 3 shows very clearly the form and outline of the tile made by Mr. Robinson. These tiles were no doubt made from the same clay, and burned in the same kilns, as the brick which Mr. Robinson manufactured. The house has long since been destroyed, but the old stable withstood the ravages of time and storm until 1907. It was razed to make way for

[1] Barber, E. A. Pottery and Porcelain of United States, p. 51.
[2] *loc. cit.*
[3] *loc. cit.*
[4] Howe's History of Ohio, Vol. 2, p. 301.

a fine library building. The photograph shown in Figure 4 was taken just before the work of destroying the old building was begun.

The view of the stable shows the roof in a dilapidated condition, not from the failure of the tiles or brick in the structure, but from the rotting of the wooden beams and rafters, so that they could no longer carry their load.

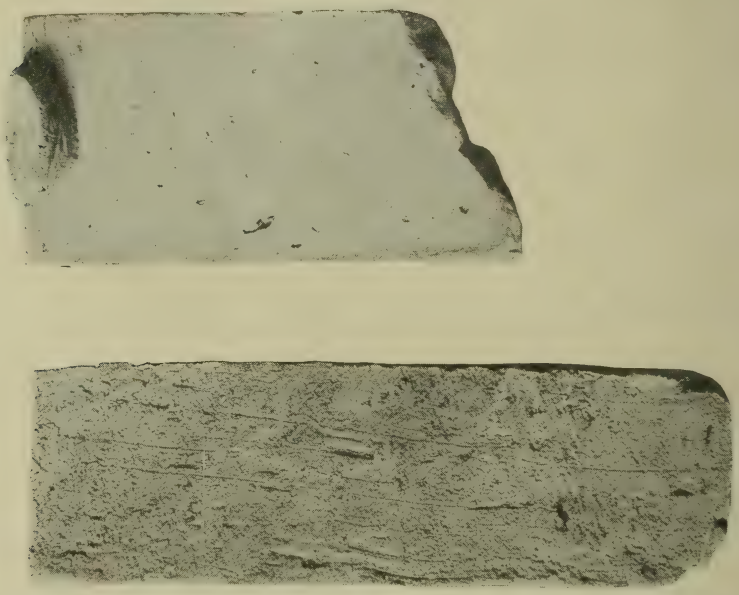


Fig. 3—Robinson's Tile, made at Germantown, Ohio, about 1814.

To the right in the picture stands a corner of the new library building, upon which can be seen roofing tiles of modern manufacture. A more striking contrast could scarcely have been found, the one tile showing the marks of time and the primitive methods of manufacture of a century ago, while the other presents a roof of the present day.

The Robinson tile at Germantown was probably a sporadic case only, and does not probably stand for the introduction of the industry, as we have no evidence that he manufactured tiles for other than his own needs.

Unquestionably, the next step in the production of roofing tile in Ohio was taken by the Zoarites, a German religious sect, who settled in Tuscarawas County about 1820, and built a town which they called Zoar. The manufacture of roofing tile by these people was upon a much larger scale than the early efforts of Mr. Robinson at Germantown, as practically all of their buildings were tiled. One only has to look upon the many old roofs that can still be seen standing today at Zoar, to

recognize that the use of roofing tiles was not new to the people of Zoar. They came from a country where tiles had been used for centuries before they sailed away to build their Utopia in the wilderness, where they could be free to follow their own beliefs. The Zoar community has disbanded after a communal existence of about eighty years, but their honest workmanship and care have left buildings and roofs which will last for many decades to come.

Fig. 4—Building covered about 1814 with Tiles made at Germantown, Ohio.

These Zoar tiles are shingle tiles of the pattern known as the "Beaver Tail," the outline and style of which can be traced back to their native town, Wurtemburg. The tiles were all hand made; the clay was dug in the nearby fields, hauled to the tile yards by oxen, dumped into soak-pits, where water was added and the clay allowed to stand till soft. After soaking for a day and night, men tramped the clay with their bare feet until it was properly kneaded or pugged. It was then covered over with straw, weighted with rails or boards, thus keeping the clay plastic until needed by the molders. It was then spaded out, and carried by hand to the small workbenches of the molders. Wooden molds were used, which were previously wet and then sprinkled with sand. The molder first took up a lump of clay, which he rolled into a long tapered roll,

similar in shape to a loaf of rye bread. This roll of clay was then thrown or slammed forcibly into the center of the mold, and the molder, using his forearm and hand, would hammer or manipulate the clay until it completely filled the mold. The excess clay was then scraped off with a straight edged stick. Ordinarily the tile would have been considered complete at this point, but by observing the tiles shown in the illustrations, it can be seen that their faces have been grooved with gutters, or lines running lengthwise of the tile. These grooves were produced by the fingers of the workmen, each finishing his tile with lines that seemed most appropriate to him.

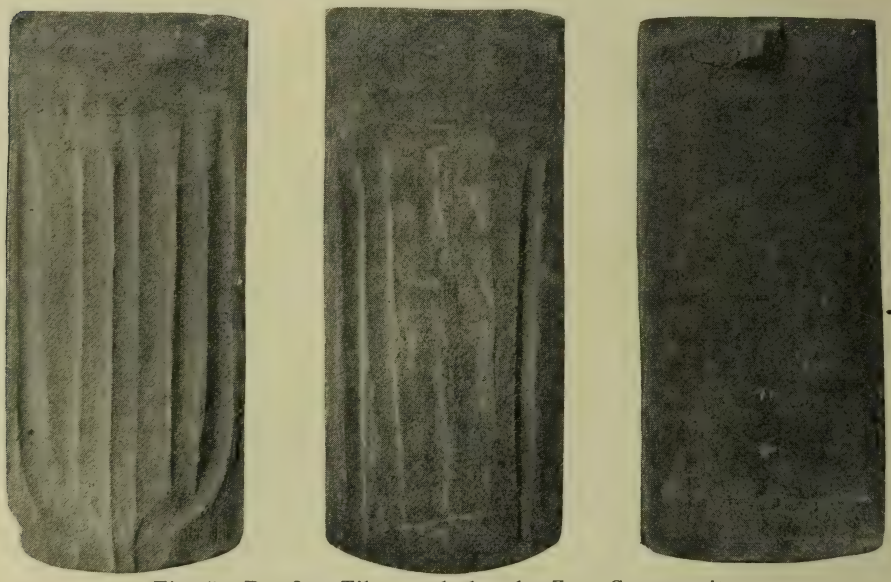


Fig. 5—Roofing Tiles made by the Zoar Community.

A two-fold purpose was filled by these grooves: first, they broke the monotony of the otherwise plain tile, and secondly, they furnished a means of keeping the rain water away from the lateral joints.

The tiles were carried from the molding benches by boys, to drying racks or floors, where they were emptied out from the molds and left to dry. The mold was carried back to the work bench, where it was first dipped in water and then sprinkled with sand, in readiness for another operation.

The burning was carried on in up-draft kilns similar to the up-draft clamp kilns used by manufacturers of soft mud bricks at the present time.

Tile manufacture was carried on by these quaint people until about 1852, when it was discontinued. As at Germantown, the tiles made at Zoar were not designed for commercial purposes, but merely to be used on the mills, store houses, shops, houses and barns of the Zoar community, amounting in all to a considerable number of structures.

The next step in the evolution of the manufacture of roofing tile in Ohio and probably the earliest establishment of the industry on a commercial basis in the United States, came during the year 1871, when Mr. J. B. Hughes of Terre Haute, Indiana, received letters patent on roofing tile of interlocking design, and at the same time on a machine to make such tiles.

Fig. 6—Old Church at Zoar, Ohio.

Among the first to become interested in the Hughes tile, was John W. Conrade of Zanesville, Ohio, who during the year 1873 purchased the right to manufacture the Hughes tile. Mr. Conrade opened a small plant during the fall of the same year and carried on the manufacture of the tile during the following winter. No roofs were covered, however, until the spring of 1874, when the residence of Mr. A. H. Watts in Zanesville was constructed with this tile. The Conrade factory did not continue long in operation.

Closely following the starting of the Conrade plant at Zanesville, Mr. Edwin Bennett at Baltimore, Maryland, embarked in roofing tile manufacture. In the beginning, the Bennett plant was also operated under the Hughes patents. Mr. Bennett was without doubt the second man in this country to take up the manufacture of roofing tile on a commercial scale. His plant was opened in 1876 and was in continuous operation up until the summer of 1908, when, owing to the death of Mr. Bennett, operations were stopped and it has since been dismantled.

Arriving in this country in 1841 from Woodville, Derbyshire, England, Mr. Bennett[1] joined his brother James Bennett at East Liver-

[1] Barber, E. A., Pottery and Porcelain of the United States, p. 192.

pool, Ohio, in a small pottery works which had been started in 1839 at that point, and which was undoubtedly the first pottery to be built at East Liverpool, and the foundation of the enormous industry which has developed there.

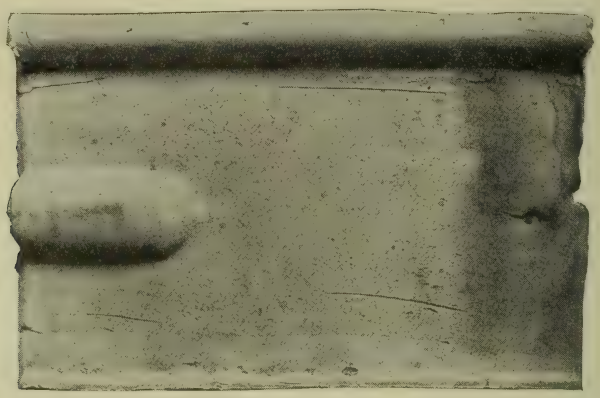


Fig. 7—Conrade Tile Taken from the Watts Residence, Zanesville, Ohio.

During 1846 Mr. Edwin Bennett severed his connection at East Liverpool, and moved to Baltimore, where he founded a whiteware pottery which is still in successful operation to-day. But, becoming interested in roofing tile in 1876, he embarked in the business in a small way. His entrance into this field was interesting, in that it marked a line of growth very unusual at that time and still so. The English potter as a rule has great pride in his craft, and a proportionate distaste for the other branches of clay manufacture, especially bricks and tiles, which he regards as on an entirely different plane from his own. But Mr. Bennett's vision was prophetic, in that he saw the ultimate importance of roofing tiles and the certainty of their use in enormous quantities, and he decided to apply his knowledge of clay manufacture to this new line. Unfortunately his efforts were largely premature, as the markets had not been at all educated to the use of tiles.

A year or so later, in 1877-78, Mr. Harris B. Camp at Cuyahoga Falls, Ohio, entered upon roofing tile manufacture.

Mr. Camp had a most interesting personality. He owned a factory for the manufacture of sewer pipes and hollow goods, and also a machine shop of considerable size, where he did a custom trade as well as building and repairing his own clay machinery. He was an inventive genius of a high order, but of the rare type that makes his ideas pay. He experimented continually, seldom doing the same thing twice alike, even when successful. He became very wealthy before his death. Mr. Camp's efforts in the roofing tile field were directed to the manufacture of the well known

diamond shaped pattern, invented by Courtois in France prior to 1856. He only continued a short time in this branch of clay manufacture, when he sold his interests to Mr. J. C. Ewart of Akron, Ohio.

Mr. Ewart took up the work with much faith and energy, and has unquestionably done as much or more than any other man to promote the use of roofing tile in the United States. The plant which he built at Akron in the late seventies was strengthened step by step and for many years held the record of being the largest and practically the only successful plant of its kind in this country, as the Bennett plant did not at any time assume large proportions, and was not largely known in the trade. Mr. Ewart's success in his business was due entirely to his energy and application. He accomplished what he did almost entirely by his own efforts, relying very little on exchanging ideas with other clay workers. He solved his own problems in his own way, and did this at a time before clay working had begun its modern expansion and control along chemical and mechanical lines. His methods, and especially his exclusiveness, did not enable him to retain the control of the business which he had by great labor secured. Opposition began to develop, and ultimately his position became difficult. He finally withdrew from the business a few years ago, the plant being taken over by the present firm, The Akron Vitrified Roofing Tile Co.

It was not until a number of years after the starting of the Akron plant, that the roofing tile business was taken up by other manufacturers throughout the state. Among them was The Repp Roofing Tile Co., New Philadelphia, Ohio, about 1893; The Barnard Tile Co., Bellaire, Ohio in 1893; Zanesville Roofing Tile Co., at Zanesville, Ohio, in 1895; another one at Ottawa, Ohio, in 1900. None of the above plants operated to exceed three or four years at the longest, and none were successful in founding successful industries. About the same time, i. e., in 1895, a plant known as the Cincinnati Roofing Tile and Terra Cotta Co. was started at Winton Place, near Cincinnati, by Mr. Jacob Freund, inspired, as many of our German citizens are, with a true love and appreciation of a good tile roof.

Starting in a very modest way, this plant was built up step by step by its founder and associates. The problems of manufacture here were studied independently and met in their own way, as in the Akron plant, and while the product was of different shape and design, the business became slowly successful. It was founded on solid experience at every step of the way, and succeeded where the other plants of its own age failed, chiefly because it was not a copy of any other plant and because it evolved its own methods.

In 1902 a roofing tile plant at New Lexington, Ohio, was erected by a company of which Mr. A. W. Brown was President. This plant, at the time of its building, was designed upon broad lines, with ample

provisions for enlargement, and, in its short career of eight years, has developed into the next to the largest, if not the largest, roofing tile plant in the United States.

Following the New Lexington plant was one at Lima, Ohio, The National Roofing Tile Co., built by Mr. A. B. Klay, a native of Switzerland. Having been born and reared in a country where tile roofs have been the main reliance for centuries, it was only natural that Mr. Klay should see the great possibilities for roofing tile in this country.

Since gathering the field notes for this report, during the summer of 1908, a company has been formed at Canton, to build a plant at Sparta, Ohio, to manufacture dry-pressed roofing tile.

Other States--Considering the establishment of plants outside of Ohio, the Mitchell Clay Co.[1] during the year 1866 undertook the manufacture of roofing tile at St. Louis. They were, however, in advance of the times and after a period of about five years they discontinued the manufacture of this line of goods.

Other attempts were made at several points throughout the country, none of which met with success until the starting of the Celadon Terra Cotta Co., of Alfred, New York, built in 1888 by Mr. Geo. Babcock. This plant was one of the pioneers, and has been in continuous operation from the time of its building. At present it is one of the plants owned by the Ludowici Celadon Co., of Chicago, Ill.[2] During 1890 a plant for the manufacture of roofing tile was built at Ottawa, Ill., and known as the Chicago Terra Cotta Roofing and Siding Tile Co. It was operated by various owners for about twelve years and then was dismantled.

About 1893 the Ludowici Roofing Tile Company was formed in this country and built a plant at Chicago Heights, Illinois. This plant has grown steadily from the start until today it ranks among the largest.

The next plants of importance were the Standard Roofing Tile Company, St. Louis, built in 1895, and the Ohio Valley Clay Shingle Company, now the Huntington Roofing Tile Company of Huntington, West Virginia, built in 1899. During the following year, 1900, the Ludowici Roofing Tile Company built a plant at Liberty City (now Ludowici) Georgia.

It was not until three years later that other plants were built. During the year of 1903 there were three plants built, The United States Roofing Tile Company, Parkersburgh, West Virginia, The Mound City Roofing Tile Company, St. Louis, Missouri, and the Western Roofing Tile Company, Coffeyville, Kansas. The next year or during 1904, The Murray Roofing Tile Company was built at Cloverport, Kentucky; following this company was the building of the Detroit Roofing Tile Company in 1906.

[1]Wheeler, H. A., Mo. Geol. Surv., Vol. XI, p. 436.

[2]Destroyed by fire in fall of 1909.

The latest company to enter the roofing tile field is the New York Roofing Tile Company at Saugerties, New York.

Other companies that are manufacturing or have manufactured roofing tiles, either alone or in connection with other clay products, are: The Alfred Clay Company, Alfred, New York; Burns and Russell, Baltimore, Maryland; Golden Press Brick Company, Golden, Colorado, Los Angeles Pressed Brick Company, Los Angeles, California; Gladding, McBean & Co., Lincoln, California; The Steiger Terra Cotta & Pottery Co., South San Francisco, California; N. Clark & Sons Co., Alameda, California; The Carnegie Brick & Pottery Co., Tesla, California; The Clay Shingle Company, Montezuma, Indiana; Spillman Brick Company, Spillman, West Virginia, and probably a number of others.

Status of Manufacture Outside of United States—Roofing tiles are now manufactured in all parts of the world occupied by civilized races. In the far East we find well established industries in China, Japan, Java, India and the islands of the Asiatic coast. The manufacture of tiles in these countries is possibly not as great at the present time, as it has been in the past, owing to the frequent relaying of the excellent tiles, made years ago by their ancestors, on modern structures.

It can be said of the Chinese, that they excel all other races in the world in their skill in the use of roofing tile. Estates and residences are generally bounded by high brick walls, crested with tiles, and even the most common country homes have at least a tile-covered gateway, while temples, shops, and all buildings of the better class are tile covered as a matter of course. Moreover, China, Korea and Japan have all treated the roofing tile in an artistic way approached by no other countries, excepting Greece and Italy.

Passing on to Persia, Egypt and the countries bordering on the south and east coasts of the Mediterranean Sea, we find that many tiles are still used, and that they retain for the most part the old normal pattern.

In Italy, Switzerland, Spain, Asia Minor, Austria, Norway, Sweden, Belgium and Holland are many thousands of tiled roofs, but these countries are not properly called large producers of roofing tiles. They do not manufacture many tiles in excess of those needed for domestic use. On the other hand, Germany, France and England are all large manufacturers of tiles. They annually produce many squares for export purposes to South Africa, South and Central America, and the West India Islands. Some few tiles are manufactured in these latter countries, but their supply is for the most part imported. At Maracaibo, Venezuela, there are two plants making tiles: The Eastern Brick and Roofing Tile Co., which has been in operation for the last fifteen years, producing roofing tile by means of a French hand-power press, and the Western Brick & Tile Co., using a similar equipment. The combined

output of these two plants is naturally small, and hence the bulk of the demand has to be met by importations.

At Montevideo, Uruguay, Mr. John W. O'Hara, U. S. Consul, reports that the majority of roofs in that country are flat, like floors, being paved or covered with flat tiles like the English "quarries," locally known as "baldosas." Many thousands of these are annually used, and he reports that in a single six months 2,537,000 were imported, largely from England.

A vast amount of business in these southern countries is yearly lost to the United States, due partly to the scarcity of roofing tile plants in this country, more especially on our southern, southeastern and southwestern sea board. At present we have only one plant in this vast territory, viz., at Ludowici, Georgia. This situation is also undoubtedly due in considerable part to our insufficient and irregular lines of communication with these countries. American ships are rare in those waters and the bulk of American exports to them go in foreign bottoms. Another cause is the lack of knowledge of our American producers as to what is wanted by these southern neighbors, and generally a tendency to impatience with their demands for special shapes and styles. The English and Germans have secured the trade, by finding out what the customs of the country require, and supplying it, while Americans have in some instances adopted a "take it or leave it" policy which is very unsuccessful in securing trade.

Some tiles are produced in Cuba and Mexico, but only in the slow and primitive manner brought in by the Spaniards three hundred years ago.

In Australia many tile plants have been put into operation by the English, German and French settlers.

Status of Manufacture in the United States.—While the first manufacturing of roofing tiles in this country has been shown in the preceding pages not to be of recent date, it is nevertheless a comparatively new industry here. We have been slow in taking up the use of roofing tiles for several reasons which are discussed in detail a little later. At present, however, American ingenuity in this field, as in many others, has triumphed over time and tradition. Although slow to enter this field, our progress since entering it has been rapid, and American tiles today have many points of excellence, and some of superiority. From the crude presses brought into this country from Germany, England and France, our inventers have developed new roofing tile machinery that leads the world in simplicity, strength and output. Many improvements in the materials of which dies are made, and also in the construction of dies, have been made in the past few years, until now the time honored plaster die is to be found in but few roofing tile plants. The chief objection to plaster dies has been that they must be renewed daily, owing

to the rapid rate at which the soft plaster surface wears away, leaving the tile made upon them with a very rough and uneven exterior, which catches dust and dirt, and soon presents anything but an attractive appearance. To overcome these objections, our manufacturers have employed dies made of such materials as cast iron, steel, brass, gun-metal, aluminium, and various alloys, all of which are being used with more or less success.

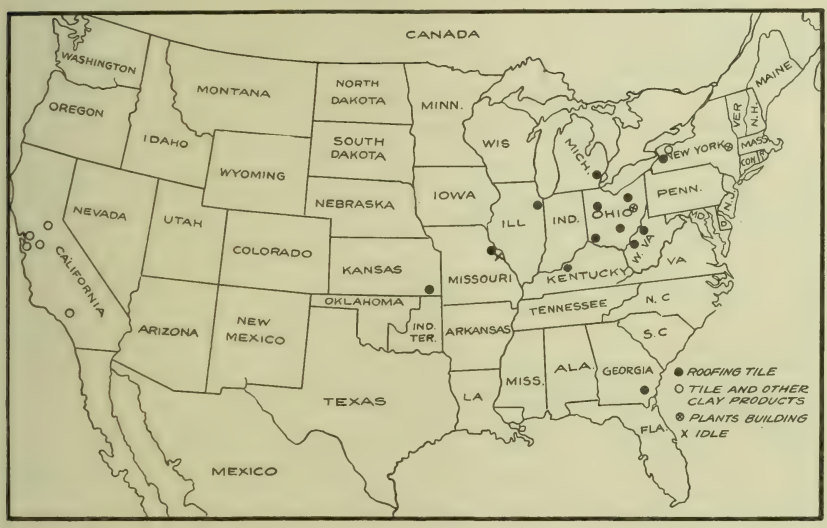


Fig. 8—Map of the United States, Showing Distribution of the Roofing Tile Plants.

In the past thirty years, the capacity of the roofing tile plants in this country has grown from the insignificant sum of from twenty-five to fifty squares per day, which is about the output of a single average plant, up to nine hundred or a thousand squares per day, if worked full time. In other words, the output has been increased from that of sufficient tile per day to cover a single medium sized building, to a number that would cover, roughly speaking, about twenty buildings of the same size.

It will be seen from Figure 8 that with two exceptions the plants are centrally located. It will also be observed that Ohio ranks first in the number of plants, with West Virginia and New York as second.

TABLE No. 1.

	No. Active Plants.	No. Building.	No. Idle.
Ohio	4	1	0
West Virginia	2	0	0
New York	2[1]	1	0
Illinois	1	0	0
Michigan	1	0	0
Kentucky	1	0	0
Missouri	1	0	1
Kansas	1	0	0
Georgia	1	0	0
California	4[2]	0	0

[1]One of these is in connection with dry press brick.
[2]All made in factories whose product covers a wide variety of clay wares. Roofing tile is not an important item in any of these plants, though made in all.

Ohio, at the present time, as always in the past, leads all other states in the production of roofing tile, as already shown. The first commercial roofing tile plant in this country was developed in Ohio, at Zanesville in 1873, and from the opening of the Zanesville plant, Ohio has, at no time, been without roofing tile industry, somewhere in her borders. Ohio manufacturers have generally kept abreast of the times, and have fought many of the hard battles necessarily encountered in the introduction of a new industry. In the face of the cheaper natural roofing materials, and also of the failure of some of the poorly made tiles and poorly laid tile roofs of early days, Ohio manufacturers have continually sought to produce more and better tiles, and to prove to the most exacting architect or builder that there is no other roofing material as nearly perfect as a well designed and well made roofing tile.

Approximately one-third of all the roofing tiles made in the United States are now produced in Ohio, and with the completion of the plant now in process of construction, the proportion will probably be raised somewhat higher.

Slow Development of the Industry in America.—Why have not tiles been used more extensively in the United States in view of their very extensive use abroad? There have been several conditions in the past which have greatly impeded the development of the industry. Some of these conditions still exist in some parts of the country. A discussion of these conditions will furnish an answer to the above question.

Firstly.—The competition of the wooden roof should be considered. The country is relatively new, and most of it originally abounded with magnificent forests of timber, suited for use as shingles. Cleared land was, and in some sections still is, at a premium, and any use to which the primeval forests could be put was gladly welcomed. While this surplusage of timber has now passed away forever in the east and central portions of the country, which are now beginning to feel the pinch of scarcity and to realize the awful wastefulness of the past, in some sections of the Northwest it is still possible to see enormous quantities

of wood ruthlessly burnt, in order to get rid of it. Thus for many years the use of other roofs than wooden slabs or shingles was very limited, owing to their cheapness and availability. As time passed and neighborhoods became towns, and towns cities, disastrous fires have occurred which have pointed out the importance of some more fire-proof roofing material, since the shingle-roofed house has formed a vulnerable point of attack in every large conflagration in this country, and in thousands of small fires. Thus the wooden roof, while still largely used, especially in the newer sections of the country, is doomed to a more and more rapid extinction, under the joint influences of increasing scantiness of wood supply, short life of wooden roofs under favorable conditions, and their constant danger of destruction by fire.

Secondly.—The competition of slate or natural stone. The conditions described as to the wooden roof have generally been first met by resort to slate, a natural stone of highly fissile character, capable of being readily sawed up into blocks of proper size, and split into very thin slabs of even thickness, which will stand further shaping and punching at the point of use.

The United States is fortunate in having a large natural endowment of slate, in widely distributed localities, and these quarries have been and will always be a source of much wealth to their communities. But slate is not free from faults, though it has many advantages which will always entitle it to an important place among roofing materials. It is cheap, easily applied, fireproof, and resistant to weather if of good quality. On the other hand, it is heavy, it is not resistant to weather if it contains soluble minerals, or easily oxidizable minerals like pyrites, or if it is not hard enough, i. e., too shaly. Also it is not very resistant to blows or strains, is not easy to repair when once laid in place, losses in shipping and application are rather high, and it makes a very plain, unornamental and uninteresting roof. The last reason is the most important of these, and were it not for this, slate would make the introduction of roofing tile a very slow and unprofitable venture. But slate only works in planes. It cannot be easily adjusted to curved surfaces, it possesses no relief, and makes a textureless roof and therefore one devoid of character, and its range of colors is limited to a small variety of blues, greens, browns and dull reds.

Thirdly.—The use of metal roofs, such as sheet iron, plain or coated with zinc or tin, and the use of corrugated or crimped or pressed iron plates has found a large field. The use of other sheet metals, such as pure zinc, copper or tin, is possible in some few cases, but in general is precluded by cost. The use of sheet iron in its various forms has the advantage of cheapness, non-combustibility, exceeding lightness, ready adaptability to any shaped structure, exceedingly rapid application, and easy repair, and easy preservation by paint applications. On the

other hand, it is very short lived unless thoroughly protected by paint or other applications at frequent intervals, and is thoroughly uninteresting in its appearance when finished, unless the pressing has gone to the extent of closely imitating roofing tile, in order to get the relief and texture. In this case, it is more costly than a metal roof ought to be, and has all the faults of any material which merely copies another.

The field of the sheet metal roof will therefore be likely to grow less rather than greater, and it will probably be confined more to factories, barns and low class sheds, and less to buildings with pretension to architectural merit.

Fourthly.—Composition roofs, made of sheets of artificial fabrics like paper, felt, asbestos, cloth, etc., water proofed with tar, asphalt, paint, and numerous patented and secret preparations, and covered with surface coatings of sand or gravel, are an important mode of covering cheap or temporary structures. Such roofs are largely confined to factories, flat roofed stores and store houses, and seldom applied to dwellings or important structures of any kind. However, they have the merit of cheapness, of water proof character to a very high degree even at low angles of pitch, of easy application and easy repair or removal. They lose their elasticity and crack and leak, if the filling material is allowed to dry out too long without renewal. They often are resistant to fire from the outside, though nearly always highly inflammable from within. The tar or asphalt roofs cannot be used on heavy slopes on account of drainage of the fluid during the summer heat. They are limited to strictly utilitarian purposes, having no pretensions to beauty under any circumstances.

Fifthly.—Cement roofing is a new factor in the market, which may be applied in two ways: 1st, as tiles made separately and subsequently applied and fastened in place, or 2nd, in sheets of reinforced concrete. Of the former, a comparison with clay roofing tiles will be made later. Of the latter, the strong points are its rigidity, its fire proof nature, its permanence when well made. Against it, lie the probability of bad workmanship (or the difficulty of securing good workmanship on which its duration and strength directly rest). Cement products in general are all open to this difficulty, that it is not easy to tell whether they are well made or not from their appearance, i. e., scanting in material or workmanship is exceedingly difficult to detect and where so much dependence must be placed on good faith, frequent abuses are always likely. Also, this style of roof is very heavy, and requires massive construction. Light or thin slabs are not satisfactory at all, as they crack if bent much or struck smartly.

Evidently, in competition with these five classes of roofing materials, most of them well entrenched in trade practice, roofing tiles have had to demonstrate their worth. Tile roofs have been unusual,

therefore not easily obtained and often causing long delays in completion of a building. They have been heavy, requiring strong construction and thus more costly. They have been poorly laid, by workmen unskilled in their use and oftentimes actually hostile to the new roof and glad to see it become unpopular on account of leaks or early repairs. They have been inherently more costly. But in spite of all these handicaps, and others not mentioned, the use of tile has increased more and more rapidly with each year. Its advantage in the hands of a skillful user, in the beauty of form, of surface texture, and of color, and its entire satisfactoriness when properly designed, made and laid, so far as weight and water-tight qualities are concerned, its uninflammable character and its actual resistance to the influence of exterior fire or water or both, its durability when properly designed and laid, all these and other advantages have been recognized by architects so thoroughly that now the great majority of large institutional buildings, fine residences, and others where architectural considerations have weight, use the tile roof. It has not yet invaded the field of the cheap roof, and it is by no means certain, under American conditions as to both labor and materials, that it ever will attain the wide usage which characterizes its use in Europe and in the Orient.

Handicaps—Some of the handicaps by which the use of roofing tiles has been limited in the past will, however, undoubtedly be removed as time goes on. In the *first* place, the design of a roofing tile, which can meet the exacting conditions of modern use, is becoming a less varied and more definite thing. Many fanciful, impractical and clumsy tiles have been "invented" or designed by various enthusiasts and their introduction has tended to hurt the cause and delay the use of the designs which are practical. Many of these theories have had to be tried out and lived down afterwards. Many of the leaky roofs and most of the slowness of tile roof construction has been due to poor design, part of it to poor workmanship. *Secondly.*—The weight of the early tile roof was excessive. Better machinery, better driers, better kilns, and more knowledge and experience on the part of the makers have overcome this objection in large part, and tile roofs are now furnished in which the weight consideration is no longer of much importance. *Thirdly*, the multiplication of plants will remove one of the biggest obstacles to the growth of the industry. With the avoidance of the excessive freight costs, and with the elimination of the delays caused by long shipments and frequently by congested factory conditions, there will come a great expansion in the use of tiles, not only from an economical standpoint, but from the side of artistic beauty, attainable by no other roofing material. With tile it is possible to get an everlasting roof in any pattern and of any desired color. The color is contained in a vitrified body, hence it is non-fading,

which is more than can be said of any other coloring compound used for any kind of a roof.

Cement Tiles—Within the last few years many patents have been taken out for cement roofing tile. Plants have been started here and there over the country from time to time, the greater majority of which have been failures. Several plants have started in Ohio, namely at Columbus, Lancaster and other points. Detroit, Michigan, also at one time had a cement tile plant. The trouble has been to produce a tile which is not too porous, and which would not crack from expansion and contraction on the roof. To overcome this, they have necessarily been made very heavy. A second strong objection has been the inability to get permanent colors. Although minerals and mineral oxides are used as colors, in the course of a single year they have been known to fade, presenting anything but an attractive appearance. Numerous roofs in Detroit covered with colored cement tiles are examples of this.

Asbestos Tiles.—A material lately come upon the market is a cement asbestos shingle or tile. This material is proving far better than the regular cement tile, on account of its extreme lightness and a certain amount of elasticity. The same objection can be made against this tile as against the regular cement tile, viz., it will prove very unsatisfactory when the question of color is considered. Furthermore, they have been known to warp badly, when exposed to the sun. To overcome this trouble a copper clamp or fastener has been devised and is being used on the later roofs of this material.

There undoubtedly will be a field for this material on large roofs of cheap construction, where extreme lightness is necessary, but for strictly first class and artistic work where something other than a flat or corrugated shingle is wanted, clay roofing tile will not likely be displaced.

Scanty Distribution of Roofing Tile Plants.—This question is perhaps the most important in connection with the promotion of the business. With at present only about one plant to three and one-half states, it is not remarkable that tiles are not more widely used. In many sections of the country a tile roof has never been seen. At the present time, not a single plant exists in our entire eastern coast region. In the entire South, only one plant can be mentioned, while the Southwest and West has not one single plant producing roofing tile as its sole output. In three or four plants in California, some few tiles are made in connection with other ware, but tiles form a minor part of the total output. When there are tile plants scattered through all the sections of our country, then we will begin to see the use of tile as a standard commodity, as bricks are used to-day. Nearly every town has its common brick yard, and nearly every state has one or more face or front brick plants, producing a high grade article, whose value will justify a freight rate to the large cities.

Thus should it be with roofing tiles. There is no present or future chance of shipping cheap tiles for covering barns and sheds. These should be made locally and carried in stock by dealers after the manner of the European countries. But the better class of tiles, such as Spanish, glazed and slipped, should be made by larger plants where proper material can be had, and shipped reasonable distances to their markets, as face brick and terra cotta are.

These conditions actually exist now, in respect to the character of plants that are now doing business. There are in practically every case well constructed and carefully operated factories, which reach their markets by long distance shipments almost exclusively. But in the furture, with three or four such plants in each of the well settled states to care for the finer trade, and with cheap tiles made in local yards for the cheaper trade, the industry will begin to compare with the development which it has reached in most other parts of the world.

From time to time statements are made in the clay trade journals by various writers, that the present day brick manufacturers should take up the manufacture of roofing tiles in connection with their present business. Such advice is extremely ill considered. The manufacture of roofing tiles is a business by itself and should receive the undivided attention of those in charge. The methods of drying, setting and burning are widely different from those of brick manufacture and attempts in the past to burn brick and tiles in the same kiln have proven in a large measure a failure. In addition, the practice is not economical. The tiles can be burned in a much shorter time than the brick, hence it is a waste of time and fuel to hold the tiles under fire, waiting for the brick to receive the necessary heat treatment.

There is no more reason for associating the manufacture of roofing tile with that of brick and drain tile, than for associating the manufacture of terra cotta with the same articles, or the manufacture of crude stoneware with fine porcelain.

CHAPTER II.

THE VARIETIES AND QUALITIES OF ROOFING TILES.

In making a critical analysis of the relative value of roofing tiles in comparison with other roofing materials, we see that in this country at least, the quality which enables this material to survive the attacks of competition and grow in spite of its greater cost, is its beauty, or the artistic quality which enables the architect to make the roof of a structure an ornament instead of a necessary disfigurement. The beauty of a roofing tile depends on two factors, viz., its shape or design and its color. Of the two, the design is more important, for with an uninteresting color (if not actually disagreeable) an attractive roof may be made if the design of the tile is cleverly handled, while with a poor design, even a tile of good color does not make an interesting roof.

But the possession of an artistic design alone is insufficient to justify the use of a tile roof. The properties of the material itself, its ability to resist weather, and its ability to resist the blows and accidental stresses of shipment, storage, application, and use, in short its strength, and also its weight in comparison with other roofs, all these must be considered. The qualities of a tile are therefore properly grouped along two lines, viz:

Artistic—design and color.

Practical or Utilitarian—durability, strength and weight.

GENERAL DISCUSSION OF VARIETIES.

The old adage, "There is no new thing under the sun," is as well exemplified in the design of roofing tile as elsewhere, for any critical examination of the tiles of the present day compared with those of ancient times shows at once that we are now merely ringing the changes on the same old fundamental shapes which man's brain evolved early in the world's history. We have, it is true, greatly modified and improved them in details, but we have not and cannot get away from the original type forms.

All roofing tiles may be divided into three great groups, viz:

1.—Shingles or Flat Tiles.

2.—Spanish or Normal Tiles.

3.—Interlocking Tiles.

Shingles or Flat Tiles—This pattern is the simplest of all; it is nothing more than a generally rectangular slab or plate of burnt clay,

about six inches wide and fifteen inches long, with holes punched at one end for securing it to the roof. In the eastern hemisphere, a lug or projection of clay is formed on the under side of the tile at the upper end, whereby it is hung on the roof purlin which supports it. Tile of this pattern make a very plain-looking roof. From a distance, the outlines of the individual tiles are lost, and the entire roof surface appears as though covered with a single coating of some red material. Upon drawing nearer to the building, the butt ends of the tiles form faint horizontal lines across the roof, but outside of these lines, very little else appears to break the monotony of the surface. To overcome this monotony, shingle tiles have been designed with quite strong vertical ridges and valleys, or the sides or edges of the tiles are made in a semicircle, so that when two tiles are placed side by side, a strong shadow line is thrown by the projection. Other patterns are also made, which have an increased thickness at the lower end over that of the upper, and in addition strong vertical ribs are added, thus making a much more impressive appearance. There are also numerous patterns of shingle tiles at the present time which have been made interlocking. All of these modifications tend either to break the monotony of the otherwise plain tiles, or to reduce the weight or number per square, or otherwise improve the roof.

The simple flat shingle when properly made, that is, straight and true, and when laid with the proper lap, makes a perfectly water-tight roof. Makers of other patterns often seek to discredit the shingle tile, by claiming that it is not water proof. It is true that a number of instances can be cited in this country in recent years where shingle-tiled roofs have failed to make a good water-proof covering. Upon a careful investigation of one of these unsatisfactory roofs, it was found that the tiles were very poorly made, being not only defective through side checks or cracks, i. e., checks extending in from the edges of the tile from one to three and one-half inches, but they were also very crooked, many of them being so warped that they were one-half inch or more out of true. In addition, they were very rough from careless handling while soft. Using tiles with the above defects, it would only be natural to expect the resultant roof to leak. The tiles described above were made about eighteen years ago, when the methods of manufacture were not well developed, and this particular roof happened to be the first contract taken by a company which was just beginning operations. Nevertheless it would have been possible to have sorted the tiles more closely, discarding the cracked and crooked ones, and thus have saved the roof from giving constant trouble for eighteen years, and its final replacement with other tiles. Shingle tiles as made today are greatly improved, and if properly laid should furnish a perfect roof.

The one great objection to the shingle tile design is its great weight,

which largely exceeds that of the other styles. While they are in the same class with a slate roof in weight, they weigh from 200 to 400 pounds per square (100 square feet) more than Spanish or interlocking tiles. They are also unpopular with roofers, from the fact that it takes so many tiles to cover a square (with ordinary sizes, about four hundred). To properly fasten these, the roofer must drive 800 nails, while with Spanish tiles about 160 cover a square, making only 320 or less nails to drive. It can thus readily be seen that it will require nearly twice as much time to lay a square of shingle tiles as it does for a similar area of Spanish tiles.

Architecturally, shingle tiles should be used on small structures only, owing to their being made in small units. Their size prohibits their use on large massive buildings, at least from an artistic point of view. For residences, park buildings, siding purposes, etc., where the roofs are not too elevated, shingle tiles make a very satisfactory covering.

The Old Spanish or Normal Tiles—This design has, without question, been used in more parts of the world than any other. While there are many modifications of the normal tile, from the simple half-round trough to the modern S tiles made on an auger machine, or the improved interlocking Spanish, they have no doubt all sprung from the ancient pattern such as we find used on the Temple of Hera in Greece about 1,000 years B. C.

To describe all of the many forms and modifications of the normal tile would be impossible and useless as well. The following notes will be restricted to the more important forms in use at the present time.

The real or typical normal tile is a trough shaped piece of clay ware of a more or less flattened semi-circular cross-section, enough smaller at one end so that the exterior of the small end will fit into the interior of the large end and thus provide for the necessary lap. The troughs are thus seen to be half sections of the frustrum of a cone of slight taper. The length varies from twelve to eighteen inches.

For the execution of certain styles of architecture, these half round pieces are placed on the roof so that one-half of the pieces act as covers for the other. That is, two rows of the half-rounds are carried up the roof inverted, or with the troughs up, and just far enough apart so that a single row, trough down, will interlock with the two inverted rows, thus forming a cover for their edges and the space between.

Another mode of using the typical normal shape is in connection with pan tiles, that is, flat tiles like shingles, but with the two edges turned up to form marginal ridges. When the half-round tile is laid in combination with the pan tile, the combination is known as the Roman design. While the original Spanish or normal tiles and the Roman designs are both manufactured at the present time, their use is ordinarily restricted in the United States to an occasional structure, where it is desired to

copy some ancient styles of architecture. For instance, there are many buildings in California and the southwestern United States, which are planned on the so called "Mission" type of architecture, which was the architecture introduced in that region by the Spanish padres who came up from Mexico, or from Spain direct, to establish their religion among the savage races who were then the sole occupants of that land. For these modern "Mission" buildings, modern tiles in the old Spanish designs are wanted, and in some instances, Mexican workmen are imported to make by hand and apply the crude Spanish tiles in the way that has been done for three hundred years in their own land, and thus give the roofs the characteristic texture and aged look which cannot be obtained with a machine-made product. For such purposes, the pure Spanish design is of course valuable, but when the questions of manufacture and use are considered, the old Spanish or normal tiles are not desirable, owing to the large number of pieces required to cover a square, and with the Roman style, it becomes necessary to maintain two sets of dies and pallets in order to provide the two forms required.

For severe northern climates, where rough winds are encountered, this kind of tile must be laid in an elastic roofing-cement to get a waterproof roof. As the tiles have no head and heel locks, and only overlap three inches, it becomes necessary to stop up this lap joint to prevent the wind from blowing the water up the joint between the two tiles and over the upper end of the lower tile, thus causing a leak.

The elastic cement mentioned is a compound consisting of some organic oil, with some mineral of red color, such as iron oxide or ore. This mixture is worked up to the consistency of soft putty and is applied in a thin layer, by a small trowel, to the upper end of the lower tile; then the overlapping end of the upper tile is bedded into it. Thus the two tiles are stuck or bound together, although there remains sufficient elasticity to permit of expansion and contraction of the roof. For this reason, a cement which sets or hardens, like plaster of Paris or Portland cement, cannot be used. The drying out or hardening of the elastic cement mentioned above is sure to occur in time, and when it occurs, it will crack under the strains brought about by changes of temperature and wind motions, and leaks begin to develop. Just what the life of these elastic cements is, has not been ascertained. One roof which had been on twelve years was examined by the writer and the cement was still plastic, and could be worked up into a paste between the thumb and finger. However, any design of roofing tile which depends on an elastic cement to make it a perfect roofing material is in default, because the life of the roof is that of the cement used, and relaying a roof is always an expensive and unsatisfactory task. Some tiles will always be broken in taking up and their color could not be matched in any new tiles, and the result would be

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a patched appearance. This and the cost, which would be in excess of the original laying, on account of the cleaning of the old cement off before relaying could be done, makes it impractical to consider a method as commercially sound which calls for the use of an elastic cement.

Modern Spanish or S Tiles.—The difficulty of manufacture of a conical trough-shaped tile has made the use of the pure Spanish tiles an unusual thing, except in Mission architecture, as noted, but the beauty of the effects secured by their use is so great that there have been many efforts made to get a design which would avoid the tapering form, and still retain the same general effect. This has resulted in the development of the S tiles.

The S tile, as at present made, is in cross section the shape of a flattened letter S, laid with its vertical axis horizontal. In the true S tiles, each one consists of a parallel ridge and trough, but a modification is also in use, in which the trough is flat with an edge upturned vertically, while the ridge is curved in a half round as before. This shape is virtually a pan tile and Spanish tile in one piece, and does away with a part of the objection to the real pan tile. Both of these two styles fall under the general head of S tiles. In order to allow for the lap of the tiles, they are so made that the faces and backs of the tiles are of the same radial length. Thus they can be nested, one above the other, indefinitely.

These tiles, either the pure S tiles or the S pan tiles, have the same fault as the ones last described, viz, for ordinary roofs, it is necessary to use an elastic cement at the upper end of each piece at the point of overlap.

It has been the practice in many instances of late to lay roofs of these tiles dry, i. e., without cement. For roofs of any ordinary pitch, this practice is to be condemned, for in this case the roof must depend on the felt or building-paper, which is laid on the sheeting and under the tiles, to prevent wind suction. Also the tiles are nailed to the roof, and the felt paper is necessarily badly punctured, and is therefore not at all waterproof. Although no elastic cement will last indefinitely, it will at least for many years, and add very greatly to the value of the roof.

Although the auger machine S tile, or modern Spanish, has this one objectionable feature, it is nevertheless destined to be the form of Spanish the most largely used in the future, on account of its cost of production being lower than that of the press-made or interlocking Spanish tile, as it is run out in continuous bar form, and cut off in lengths. It can be sold cheaper than a pressed tile and will therefore be more widely used. From the architectural view point, the S tile is very good. Its strong vertical lines from eaves to ridge of a roof are suitable for buildings of magnitude and strong outline.

The Spanish design, either pure or in the modified forms, is the pattern that will be the most widely used in future work on the better

class of buildings, like churches, schools, libraries and institutions of all sorts, and possibly on large residences, but a sense of harmony prohibits the use of full-sized Spanish tiles on buildings of moderate size. Their extremely bold outlines and high relief makes an appearance of too much weight at the top of the building. This mistake is very commonly made at the present time by architects all over the country. It is largely due, no doubt, to the fact that the manufacturers are making but one size of Spanish or S tiles. However, when the time comes that our American architects more fully realize the artistic beauty of the tile roof, and perceive that this can only be developed by using tiles of proper proportion for the buildings on which they are to be used, there will be tile manufacturers ready to produce the desired varieties of sizes.

Interlocking Spanish Tiles.—Although it has been seen that the development of the S tiles has solved the problem of cheap and rapid manufacture, while still retaining much of the distinction, style and characteristic "texture" of the real or old Spanish tiles, it has failed to overcome this most serious defect, viz., the necessity for cemented joints to make the roof reliable in windy rain and snow storms. A further step has been taken in the interlocking Spanish design, to correct this deficiency. It may be objected that the use of the interlocking idea puts the tile out of the Spanish class altogether, but it does not seem so to the writer, for the name "interlocking tiles" has a distinct meaning in the trade and no tile maker or dealer would confuse an interlocking tile with an interlocking Spanish tile, if the terms were used in that way. In any case, the interlocking Spanish tile is clearly distinct from the rest of the interlocking tiles and these latter will be discussed under a separate heading. This interlocking Spanish tile differs from the S tiles made on an auger machine very little in outline or appearance, but it is made with side and end locks, or tongues and grooves on the upper surface of the tiles, which intermesh with corresponding grooves and tongues on the lower surface of the contiguous tiles. By this device is produced a perfect tile, that is, one that will not need a cement to make it water-proof. With locks of proper height, and tiles that are properly made, it is possible to lay a roof of this design that will withstand any storm except such a one as would be in danger of lifting the roof itself.

The cost of producing this tile is naturally above that of the straight auger-machine S tile, since the locks can only be put on by pressure in a tight die, but the superiority which it undoubtedly affords should insure its use on the better class of buildings.

From an artistic point of view, the press-made Spanish tiles are much better than the flow-die pattern, inasmuch as it is possible to give the butt or lower edge of the tile a rounded or curved shape which agrees with the other curved lines of the tile and make the whole consistent, while in the auger-machine S tiles, the ends are wire-cut and stand out in a sharp, harsh line in marked contrast to the flowing curves of the roll of the tile.

Interlocking Tiles.—As explained in the preceding section, this tile, unqualified by any other word, is understood in the trade to mean a pressed tile of a shape different from Spanish or S tiles, and as the name implies, all tiles of this group are made so that their edges interlock one with another. Just when the first interlocking tiles were made is not known to the writer, but it was unquestionably much more recently than either of the other two types. It is probable that they were first made in France or Germany, for it is in those countries that we find their greatest development.

The interlocking tile is rectangular in outline, and of various sizes, though at present the manufacturers have settled down very generally to the dimensions of nine inches wide by sixteen inches long. The outer surface of the tile is usually more or less broken by strong vertical lines or corrugations. On the edges are the tongues and grooves which form the locks. The right hand side of the tile is made to form the cover or upper half of the lock, while the left-hand edge carries the under half. The tongues and grooves which form the locks are made single or double or even treble.

The upper and lower ends of the tile are also provided with similar locks, so that all four sides of the tile engage with the edges of four other tiles. In cross section, the interlocking tiles are usually complex—that is, they are neither planes like the shingle tiles, nor simple curves like the old Spanish tiles, nor double or reversed curves like the S tiles. They are usually planes broken at one or more points by a curved roll or rounded elevation, the axis of which is parallel with the longer axis of the tile. Sometimes there are two such rolls, with a plane area between. Sometimes the elevation is not a curve, but is V shaped in cross-section.

The presence of this roll, whatever its form may be, strengthens and stiffens the tile materially in lines at right angles to its axis. In turn, the roll itself requires stiffening with smaller internal ribs or partitions, which hold the tile against warpage on the other axis. Thus supported by the vertical and horizontal cross ribs, this tile is a much stronger, more solid structure than any of the preceding, and consequently it is possible to make interlocking tiles in much larger sizes. Their large size or roof-covering capacity, and their lightness, due to the narrowness of their overlaps, which is about two inches on all sides, makes them much in favor with every one dealing with the subject. The manufacturer likes to make them on account of their rigidity and the consequent small loss in manufacture. Also, on account of their size, few are required for a square—about 135—and as he sells by the square, he can quote a low price. The roofer likes them on account of the rapidity with which he can cover a roof. The architect likes them because of their low weight—about 800 to 850 pounds per square—and because of their mechanical perfection and the permanence of the roof. The consumer likes them both on account of their appearance and their price.

So all in all, from a commercial standpoint, the interlocking tiles are the ones most in favor.

But, considering them from the standpoint of architectural beauty, they are seriously criticised in some quarters, and for this reason their use has largely been restricted to plain structures, like train sheds, power houses, factory buildings and others of like nature—buildings of large roof area, without much pretence to architectural beauty. They are used on buildings of the above classes, largely on considerations of cost, and for this reason the interlocking tiles are destined to be the most important commercial tiles of the world. The other tiles will always have their uses, but the interlocking tiles will surely be the standard commodity.

THE DESIGNING OR PROPORTIONING OF ROOFING TILE.

What has been said thus far has dealt with the design of the tile as a whole, and largely with its acceptability from the standpoint of appearance—the artistic side. We must now take up the more intimate phases of design, viz., the proportioning of the parts of the tile so that it will be able to resist the strains to which it will be subjected. It is one thing to select a superficial form which is artistic and which would produce a beautiful effect on a roof, and quite another to make the tiles economically and with low losses in manufacture and use. The latter problem demands correct settlement of the proportions of the tiles—length, breadth, thickness, overlap, mode of locking, and system of strengthening ribs to guard against warping or breaking. In treating this side of the subject, it will be well to again consider each of the three principal varieties separately.

Shingle Tiles—The ordinary size is six by thirteen by three-eighths inches. The thickness is often allowed to reach one-half inch, chiefly through neglecting to watch the wearing of the die and failing to replace it with a new one or to repair it with new lining. The weight of shingle tiles three-eighths of an inch thick is about 1,100 pounds per square, where one-half inch tiles will run 1,200 pounds or more. Thus the thickness should be very carefully watched.

The edges or sides of the tile are made either square or rounded. The latter form is to be preferred on both practical and artistic grounds. It is extremely difficult to continuously produce square or sharp corners in a column of clay flowing through a die. The corners tend to crack or pull up, or rag or feather-edge, due to the greater friction or resistance of the corners to the passage of the clay. With a rounded edge, the tile-bar will flow much easier through the die, and with far less probability of checking on sides or corners.

When the round-edged tile is placed on the roof, vertical lines are accentuated much more than with square-edged, close-fitting tiles, and this is a great help to an otherwise plain roof.

Again, the rounded corners form air spaces or channels at the under edge of the tile, thus providing open channels for the ventilation of the roof, keeping the sheathing boards dry, and delaying decay.

Interlocking Shingle Tiles.—These tiles are usually made nine inches wide, by thirteen inches long, by one-half inch thick, and require about 190 to the square. Their weight per square runs from eight hundred to nine hundred pounds. At the upper end of the tile on the face or obverse side, two small ribs, about one-quarter of an inch high, are so placed that one is at the extreme edge and the other about one and one-half to two inches lower down on the tile. On the under or reverse side, at the lower end of the tile, are two counterpart ribs, one forming the end of the tile. These ribs act as wind and water-breaks at the ends of the tile.

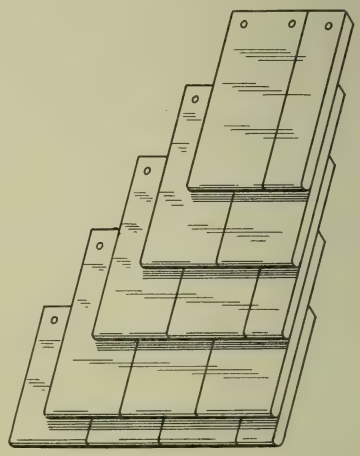

Fig. 9—Round-edged Shingle Tiles.

Along the left-hand side of the tile is a single gutter, into which meshes a corresponding rib projecting downward from the right-hand margin of each tile, thus forming the lateral or side lock.

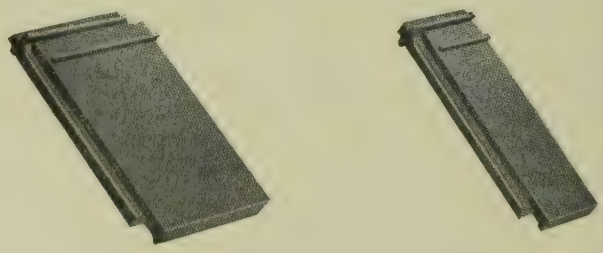

Fig. 10—Interlocking Shingle Tiles.

The greatest trouble in making this kind of tiles is to get the locks deep enough. If they are made as deep as they should be, then the butt end of the tile is too high, accentuating the horizontal lines on the roof and making them appear out of proportion or harmony.

S Tiles.—The S tile made on an auger machine is usually eleven inches wide by thirteen inches long, with an extreme height of roll of three inches, and average eight hundred to nine hundred pounds per square. The thickest part of the roll is one-half inch and the thin part about five-sixteenths of an inch. These different thicknesses are due to curves of the same radii being used on both sides of the tile in order

that the overlap may fit perfectly. It is usually better to have offsets in the die, which produce parallel grooves through the thick portions of the tile, thus not only making them a little lighter in weight, but assisting in the drying and burning as well. Tiles having these open grooves should not be laid dry; an elastic cement should be used to prevent water and snow from blowing up over the end of the tile, under influence of wind in the proper direction, The side of the tile which is covered by the roll should be made just as high as the roll will allow, thereby forming a good deep gutter.

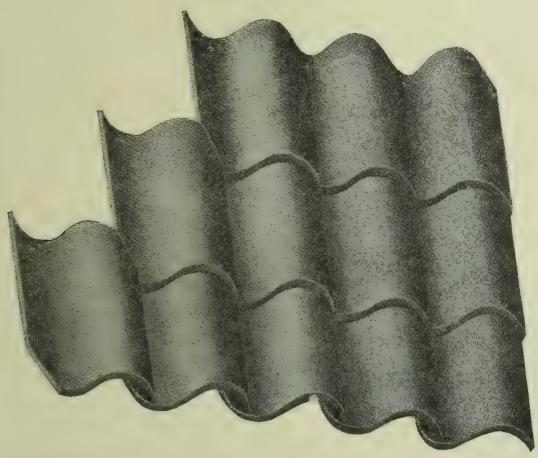

Fig. 11—"S" or Spanish Tiles, made on an Auger Machine.

Interlocking Spanish Tiles.—In general outline and appearance, these tiles are not very different from the S tiles produced on the auger machine. The real difference is in the side and end locks, but these do not show when the tiles are in position on the roof. In size they usually run about nine by twelve inches, or a little larger, and weigh about eight hundred and fifty pounds per square. In some patterns the lock consists of two raised ribs, running lengthwise, along the side of the gutter, and then crosswise of the upper end of the tile. These ribs are usually three-quarters of an inch high and the same distance apart.

Underneath the roll are two projecting tongues, which interlock with the side ribs on the edge of the gutter. The end of the tile may be made either square or rounded. The latter shape is the more pleasing and lends its form more to the shape of the rest of the tile.

To make this tile perfect, it should have a strong double lock along the side and over the top. The ribs should be fully three-quarters of an inch high, or even more, and the tongue which fits between the ribs should not quite touch the bottom of the groove, allowing room for the water to flow, thus preventing the accumulation of dirt. It is also well

not to have too close a fit, in order to avoid a tendency for this space to fill and remain damp by capillary attraction; also, there should be some play in the locks to allow for slight differences in size of the burned tiles.

Fig. 12
Interlocking Spanish Tile.

Interlocking Tiles.—In this group we find the best representatives of the interlocking principle. A few forms will be shown to illustrate not only good forms of locks for interlocking tiles, but for any other kind of tiles using the interlocking principle.

In the first place, the tile should be so designed that all high parts on the face or obverse side are in the same plane, so that a single flat pallet can be used to place it on when it is taken, soft and easily deformable, from the press. A tile in position on its pallet is shown in Figure 14.

On the back or reverse side of the tile, small cross-ribs should be provided, not only to stiffen it, but to make its nesting or packing more secure and solid.

It will be seen that the French A pattern, Figure 15, has two rather deep valleys or gutters; these carry away the greatest part of the water. Upon long roofs of low pitch, they are often taxed to their utmost capacity. The tiles should also be so designed that they break joints, i. e., the locks in the various courses on the roof should be made to alternate. Thus, the water that gets into the lock of one tile is not transmitted to the lock of the tile next below, but is turned into the broad gutter on its surface.

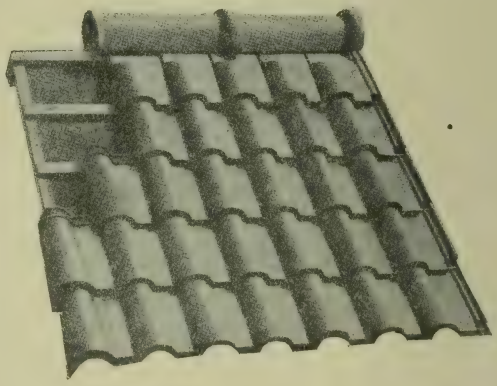

Fig. 13—Section of a Roof, Showing Interlocking Spanish Tiles.

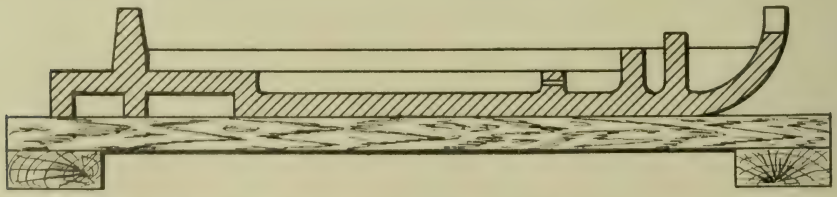

Fig. 14—Showing proper design for an Interlocking Tile to lie Flat on a pallet.

These tiles are usually made nine by sixteen inches, requiring one hundred and thirty-five per square. Each square weighs approximately seven hundred and fifty to eight hundred pounds.

On the general subject of modes of interlocking available for use in tiles, there is considerable of interest. Referring to page 42, a series of sketches show the gradual development of the interlocking idea.

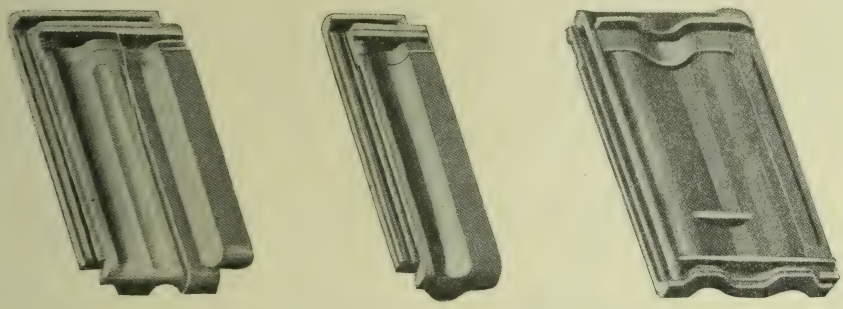

Fig. 15—Interlocking Tiles, French A Pattern.

Side Locks.—*Figure A* shows the simplest form of lock, being merely a single tongue and groove. This lock is not very serviceable. In the first place, it is too shallow, and secondly, the water can enter the open joint at the point marked (a), carrying dust and dirt with it, which soon fills the shallow place under the tongue. The water, being thus blocked, soon fills up the gutter and leaks over onto the roof boards. Tiles provided with this form of a lock should only be used on buildings of little importance, like sheds.

Figure B is a lock of a little better design, inasmuch as the shoulder at the point marked (b) will have a tendency to break up currents of air and prevent them from carrying water into the lock so freely. Also, the dirt will be more likely to lodge on the shoulder (b) and not fill up the gutter.

Figure C. This lock is a very much better one than either A or B, because the open joint is on the side, and covered by the over-lap (c), thus preventing the rain from entering the lock-joint directly. The most serious objection to this lock is the likelihood of its leaking by cross-currents of air blowing into the open joint at the point marked (c) and carrying the water with it on over the entire lock.

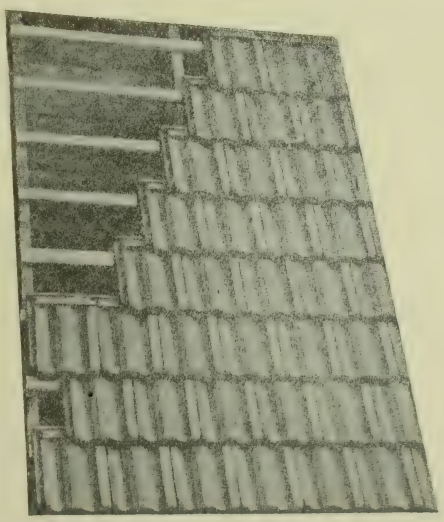

Fig. 16—Showing Section of a Roof Laid with Interlocking Tiles in Which the Locks Break Joints.

Figure D. This lock is again a very decided improvement over any of the preceding; while it resembles B, it is better, because of the protecting lug at the point marked (d) which prevents cross currents of wind and rain from entering the joint from the side, as in Figure C. Also, an improvement over B lies in the fact that an air space is left under the tongue at the point marked (d). This allows the dirt that might enter to be washed away, and also prevents the possibility of capillary attraction, which is apt to cause leaks in Figures A, B or C. The raised portion (d) also makes the depth of the main gutter of the

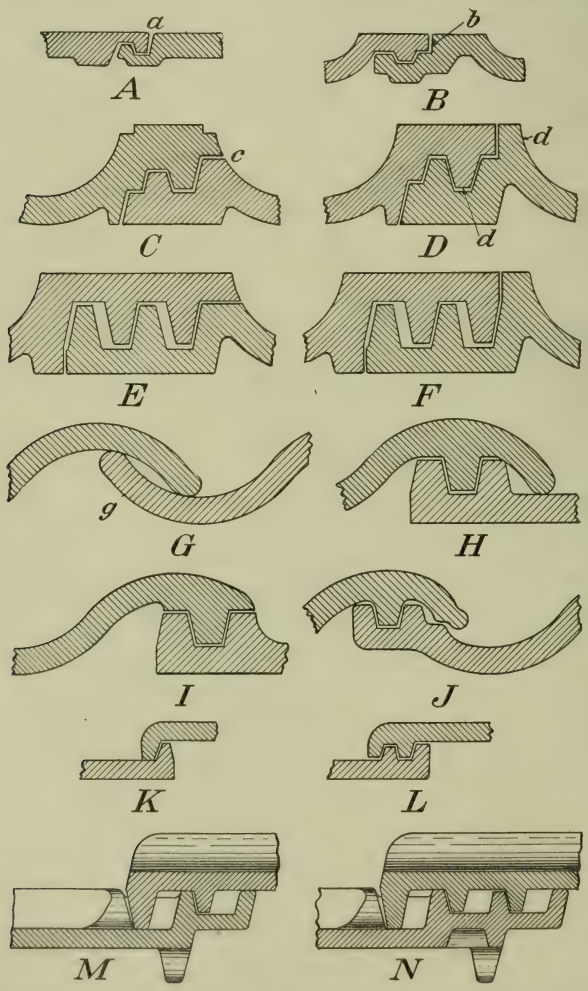

Fig. 17—Showing Various Forms of Side and End Locks.

tile deeper, which is a good feature. This lock is very largely used in this country on the principal brands of interlocking tiles.

Figure E. In E, we have a lock in some respects like C, except that it is double. These double locks make it almost impossible for

wind to blow fine snow or rain through the various turns that would have to be made. This is an exceptionally good lock, there being only one slight drawback, viz., the main gutter of the tile is not quite so deep as in D or F.

Figure F shows a double lock patterned after D, which should prove very effective. The high part at (f) makes the main gutter very deep; with the two lock gutters there should be no trouble from leakage. While locks E and F require the use of more clay than lock D, they should prove very much more satisfactory. Any snow or rain getting beyond the first lock will surely be caught by the second, thus preventing a leaking roof.

There are, of course, still other locks in use, but they are all more or less modifications of the ones shown, and bring in no new principles or added efficiency or economy in manufacture.

Figure G shows the typical lock used on ordinary auger-machine Spanish or S tiles. While this lock is simple, it is very effective. The main gutter is very deep, and the air space (g) tends to break up any capillary flow. However, if the tiles are not straight, and the two contact points are open, fine snow will very frequently blow over the tongue, and, melting afterwards, cause leaks.

Figure H is a fair representative of the lock used most commonly on interlocking Spanish tiles. It will be seen that the lock is a double one, and, as said before, if the ribs are high enough, it will make a very satisfactory lock.

Figures I and J are two other forms of locks used on Spanish tiles, neither of which has any particular advantage over H, and, in fact, are more likely to leak under the influence of winds blowing diagonally across the roof.

Head, or Top and Bottom Locks.—*Figure K* represents the most simple form of a head-lock which can be used, viz., the end of one tile turning up and the next one down. This lock is a very poor and ineffective one. Many tiles have been made with this simple lock, but the day when they can be freely disposed of has passed. The lock does not prevent wind from carrying fine snow and rain over it.

Figure L is a very much better lock and is the type largely used for the head-lock of Spanish tiles. Any snow that may pass the first tongue and groove will be caught by the second one and returned to the outside face of the tile as water.

Figure M represents the typical head-lock for interlocking tiles other than Spanish. It is the one mostly used in the United States, and as a rule proves very effective. It can, however, be improved for open construction work by using the head-lock as shown at N.

Figure N. This is a triple head-lock and should remain dry throughout any storm.

The most vulnerable part of a tile is the joint, both on the side and end. Many of the first tiles used in this country failed to make dry roofs by not having the locks either large and deep enough, or in sufficient number. More attention is being paid by tile manufacturers to the perfection of the locks each year, and such should be the case, for the future of the industry absolutely depends on its being able to furnish strictly water-proof roofs for important structures. It is quite probable that there will always remain a field for the use of tiles of such a grade that they will remain tight under all ordinary storms and might leak *a little* under severe and exceptional stress, for there are many buildings in which a slight and well diffused leakage, separated by wide time periods, would do no real harm. If tiles for such purposes can be made at decidedly lower figures, they will unquestionably find use, but such tiles ought to be sold on this understanding. The trouble in the past has been that the tiles of this grade have been sold under a short-sighted business policy as being fit for a roof of first grade, while, as a fact, they belong to and are fit for only a roof of second grade.

There are also many roofs which may leak more than a little with every windy rain, but which are still good enough for their purpose, and the cheapest grades of tiles without any locks, or only the least efficient, will surely find use for such purposes.

What is needed in the roofing tile business at present is some classification of the product according to its purpose. It is manifestly unfair that the leakage of a cheap tile on a roof of small importance should be considered as an indictment against tile roofs in general. If a tile manufacturer guarantees a roof as water-proof under any or all natural conditions, and it fails, then his blame and responsibility are unquestioned. But if he sells a roof for what it is, then the architect and consumer have no just cause for complaint.

THE RELATION BETWEEN THE DESIGN AND THE PHYSICAL PROPERTIES OF A ROOFING TILE.

It has been shown that the selection of a design for a roofing tile involves a consideration, not only of the artistic results attainable by the use of the tiles in masses, and of the ability of the tiles to collectively make a dry roof, but also of the proportioning of its parts to develop the required physical strength for handling, piling in driers and kilns, storage, and fastening to a roof. The question of color is one that is largely separated from considerations of design, being usually a fixed factor with any single clay, though sometimes regulated by mixture of clays or addition of coloring compounds to them or covering their surface with colored coatings.

The question of the strength of the resultant tile, then, must always be kept before one in designing a tile—any neglect of this point will result

in heavy losses in manufacture and generally by breakage or leakage after application on the roof, owing to inability to stand the shocks and strains incident to ordinary use. This question of the proportions or sizes necessary to give the requisite strength is one which cannot be settled by any arbitrary rules or principles. If clays were a fixed and definite material, or even nearly so, as steel or glass, it would be possible by experiment and calculation to reach a standard ratio of thickness to area, and a minimum of reinforcement or filleting at corners or points of abrupt change in direction of the body of the tile. But since clays in general are anything but fixed or definite, and since even the same clay develops very great variations of strength at different stages in its burning process, and is moreover often subject to fluctuation in quality in the same bed, it is evident that the selection of a design for a tile can only be a tentative matter, and that the tile ultimately developed is very apt to differ more or less widely from the design selected in the beginning. The tile-maker is likely to find that his clay will not flow in a stream of the desired cross section, or that it will not release well from a die of the desired complexity of shape, or that it must be made heavier to endure drying or burning without warping, or that new ribs and reinforcements, not needed or desired, so far as water-proofness is concerned, are required to keep the ware straight and strong. Therefore, a tile design in successful use in a factory almost invariably represents a process of adaption or adjustment between the ideals of design on the one hand and the capacities of the material on the other.

It is not the intention to discuss at this point, the intimate physical properties of the roofing tile bodies as to strength per square inch, etc., but rather to consider broadly the sources of the strength of the product, and the relative desirability of the different internal structures which clay bodies of different sorts are known to develop, especially under the influence of different heat treatments.

The strength of a burnt clay ware is dependent on:

1st. The plasticity or internal cohesion which the mass exhibited in the unburnt condition.

2nd. The assortment of the sizes of the mineral grains composing the mass.

3rd. The extent of the alteration of volume of the mass in drying and vitrification.

4th. The degree of combination, or vitrification of the mineral grains in the burning process.

5th. The cooling of the product from the nearly-fused condition to the atmospheric temperature without inducing cracks or cooling strains.

Taking them up for consideration in order:—

1st. It is a point well known and recognized by clay workers that those clays which show a high degree of internal cohesion or sticking

quality, with which is always associated good or high plasticity, are apt, other things being equal, to make a strong, tough product when burnt. There are doubtless exceptions to this rule, but the use of the adjective "strong" by so many clay workers is a tacit recognition by them of this point. Strong or fat clays, i. e., tough, adhesive, cohesive, plastic clays, make strong products, compared to the products made from "weak" or lean clays, whose properties are the reverse of those above listed.

The bearing of this in roofing tile manufacture is that clays of the lean or weak class are not suited to this purpose, and if used, as they sometimes are, will require extra fitness in other directions, or extra care in firing to make up for this deficiency. In general, roofing tile manufacturers are divided into two hostile camps, producing, respectively, soft, porous tiles and hard, impervious or vitrified tiles. The soft, porous tiles are almost always produced from glacial or alluvial clays which are "strong," and the strength of the tile in its unburnt state is comparatively little increased in the burning process. The hard, vitrified tiles, on the other hand, are frequently, if not usually, made from shales or indurated fossilized clays, which have lost the most of their plastic character during their long existence in rock form, and only developed a partial or feeble cohesion and plasticity in tempering. These clays are "weak" and make a tile which is physically weak and easily broken in handling in the raw condition. But this defect is overcome by their fitness to develop strength in burning. They vitrify well and their product is able to stand alll the physical tests to which it can fairly be put, with credit.

2nd. The assortment of the sizes of the mineral grains of a clay is of importance in two directions—its effect on the strength of the raw clay and its effect on the ease of vitrification in burning. It has been shown that a mixture of coarse and fine particles, in graduated sizes from the finest slimes up to medium sized sands, is productive of tensile strength in an unburnt clay. A clay composed of all fine particles has been found by a number of observers to develop usually only moderate or low strength. The same facts are found to apply to cement concretes where a proper mixture of sizes is a matter of rigid requirement in the sands, gravel and broken stones used in work of importance.

In the glacial and alluvial clays, commonly used in making porous roofing tiles, this variety of sizes of mineral particles is usually found. The fine sizes especially are well represented, insuring the filling of the voids between the coarse particles. In shale and fossil clays, commonly used in making vitrified roofing tile, the ultimate mineral particles are usually very fine indeed, but in grinding and tempering, the paste which is formed is not composed of its ultimate mineral particles. Its grains are usually aggregates or lumps of grains, sticking together and acting

as single large grains, and there is usually a deficiency of fine material. Hence, the product is weak in its unburnt condition.

After burning, however, these relationships are altered. The relatively coarse-grained glacial and alluvial clay, with a large variety of sizes of grains in its component minerals, usually vitrifies slowly and the structure is apt to be porous and less compact when fired at moderate temperatures. But the shale grains, which acted in clots or groups in the plastic state, act more nearly at their true size value in vitrification, and a greater degree of consolidation and body-knitting takes place than in the other case. So that the assorted sizes of grains is found to most generally favor the production of porous tiles, while the use of clays of uniformly fine grain is apt to produce dense, vitrified tiles, all other things being equal.

3rd. The effect of large volume-changes on the strength of the product is a factor of importance. It cannot be considered as operating separate from the considerations Nos. 2 and 4, but its influence can be clearly seen in connection with these factors. In general, excessive volume-changes lead to weak, structurally defective products This is true, whether the change in volume occurs in drying or in firing. This may seem paradoxical, because extensive volume-changes are necessary to develop a highly vitrified structure. But there is a golden mean here as elsewhere, and clays which undergo great shrinkage almost invariably develop at the same time internal flaws, or laminations, or "dry spots," representing the inability of the mass as a whole to contract at the same rate in all directions on account of its shape, or the influence of pressure of other pieces of ware resting on it or similar causes. The result must mean flaws at right angles to the directions in which high tension develops.

Thus, roofing tiles made from glacial and alluvial clays, which shrink at a moderate total rate, usually retain a sound interior structure, and are little weakened by interior flaws, while the tiles made from shales, whose volume-changes are high, in vitrification at least, are often considerably weakened by shrinkage-cracks inside the shell of the ware. Examples can be found in both groups of clay where these properties are reversed, but the above is true in general.

4th. Any clay, on firing, goes through a considerable series of changes or stages from the comparatively weak or unstable raw condition to the comparatively strong and permanent burnt condition. The changes are usually in the direction of increasing density, increasing strength, increasing shrinkage, decreasing porosity and decreasing specific gravity. But in any clay, a point is attained when these changes reach a condition of balance—when the clay is at its best—and further increase of heat leads to a reversal of all these properties. That is, the clay grows less dense, less strong, bloats instead of shrinks, and develops

marked porosity. The strength, therefore, will vary quite widely, according as the burning process is stopped before this culmination, or at it, or subsequent to it.

In the glacial and alluvial clays, the burning is customarily stopped considerably short of the culmination point of the clay's heat treatment, and while its strength is still undeveloped. This is done to retain in the product the quality of porosity, to which a high value is assigned, for reasons discussed later.

In shale clays, the burning is generally carried to fuller maturity and the properties attained represent approximately the greatest strength and minimum porosity which the clay will develop. This is done on the theory that a dense vitrified body is the best for roofing-tile purposes. It will be seen, therefore, that the two hostile camps, advocating respectively porous and vitrified tiles, select their materials, treat them, and fire them, all with a view to developing these two divergent sets of properties.

5th. The cooling of any highly heated clay body is attended with risks—sudden cooling will crack practically any clay product and the thicker and more thoroughly vitrified it is, the more certain it is to undergo cooling strains in excess of its resisting power. Therefore, those who favor the vitrified roofing tiles must take a constantly higher risk of loss in handling their product, than those whose product is porous and which will therefore stand cooling with less likelihood of dunting.

The development of strength has been shown in the preceding discussion to be conditioned on a considerable number of allied and interdependent factors. It has been shown that the pushing of a clay body to that stage of burning which will produce the maximum of strength cannot be done without producing other changes which to some extent are contrary to or harmful to the production of a desirable product. It therefore becomes a matter of judgment, for each manufacturer to decide for himself.

POROUS vs. VITRIFIED ROOFING TILES.

As before stated, this question is an ever present one in the roofing tile industry, and in the nature of the case it is one which never can be settled, for as long as men's minds work independently, so long will the facts be subject to different interpretations.

Numerous examples of ancient roofs covered with both kinds of tile can be pointed out which have by no means gone to pieces, or given any other trouble. Hence, at the outset it must be admitted that each side is partly in the right so far as claiming good qualities for its own product is concerned, and in the wrong in most that they say about the bad properties of the other kinds of tiles. While it is a fact that more roofs built of porous tiles have gone to pieces than in the case of the vitrified

ones, it must not be overlooked that there are hundreds of roofs built of the porous variety to single ones of the vitrified. A comparison, to have value, would have to consider *percentage* of failure in each case. For instance, in France and Germany, the two largest tile centers in the world, the manufacturers are producing hardly anything but the porous tiles. Tiles that have been on roofs in those countries literally for centuries have been found to absorb a high per cent of water. This fact alone should show that a high degree of porosity is not necessarily proof of inability to stand frost and bad weather.

As to the vitrified tiles, no one questions their durability when once in position, but there is an objection to them which is well founded.

It frequently happens that tiles are laid upon a roof of open construction. That is, the roof is not sheathed solidly in the usual manner, but the tile are hung on wooden or iron purlins, spaced apart horizontally on the roof just so as to accommodate the length of the tile. When a roof is so covered, and the roof is examined from beneath, the under side of the tiles are open, or exposed to view.

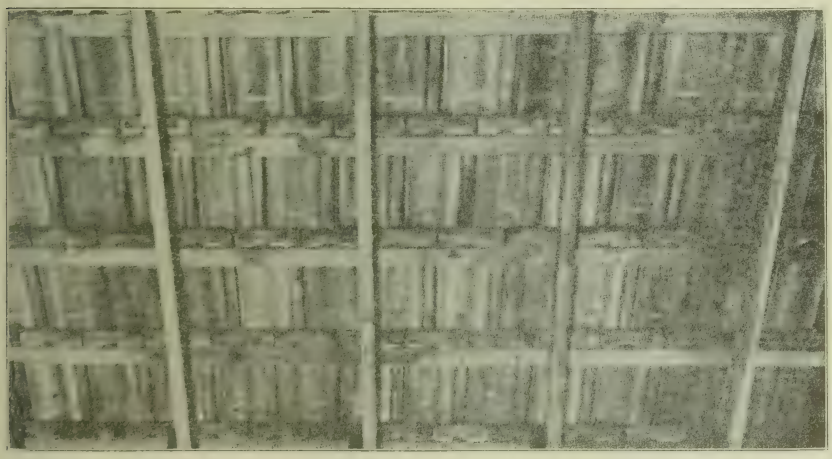

Fig. 18—Under Side of Open Construction Roof.

For various reasons, among them fire protection, many roofs of the above style are used on boiler rooms, power houses, storage houses, and buildings of like nature. It very frequently happens in cold winter weather that the air in the interior of such a building becomes of high humidity. Such air, upon rising in the building, will come in contact with the under surface of the cold tiles, and will deposit water as dew upon them. Should the roof be very steep, the water thus deposited may, in the case of vitrified tile, course along down from tile to tile, but under ordinary conditions it will form drops or beads of water, which will in time reach a size where they will drop off or drip. A dripping roof often causes much damage and annoyance where expensive machinery or material must be kept dry,

The above tendency of vitrified tiles to form dripping roofs has been the chief argument of the maker of porous tiles against his opponent. He has claimed that porous tiles under the conditions set forth above will never sweat or drip, but instead, on account of their porosity, will absorb the moisture, and gradually evaporate it into the atmosphere on the outside. The fact that it is only in places of the sort described above, and in roofs built as above, that trouble from dripping is observed, is a point in the controversy seldom mentioned by the maker of porous tiles.

The tendency of soft-burned clay products to disintegrate by frost action has been mentioned, and it has undoubtedly caused the failure of an occasional tile and an occasional roof, but it is not a common defect, and it does not occur in many cases when the extreme porosity of the tile seems to invite it. In order to understand this fact it will be necessary to study the clays used, and the method of manufacture pursued.

With very few exceptions, porous tiles are made from the soft or unconsolidated clays, of alluvial or glacial origin, while the vitrified ware comes largely from shale. The fact that few soft clays will stand vitrification in thin wares, like roofing tiles, while shales as a rule will, shows why one kind of clay and one kind of tiles are thus associated. The manufacturer using shale under the ordinary methods of preparation knows that his ware will be too weak and porous, and that it will not stand up under freezing and thawing conditions unless it is well vitrified. Thus each manufacturer is giving the treatment which his material requires, and is doing so under necessity.

The question now arises why, if many roofs of porous ware stood for centuries, is it necessary for the user of shale clays to vitrify his product?

This subject as applied to bricks has received recently very careful treatment at the hands of Mr. J. C. Jones,[1] a digest of whose article follows:

Taking bricks of different degrees of hardness as manufactured from different clays by the soft and stiff mud processes, after determining their absorption and porosity, they were then subjected in a completely saturated state to a severe freezing test, extending through twenty freezings and thawings. The bricks were then crushed, together with unfrozen duplicates, in an Olsen testing machine. The following table shows the results of the freezing test.

[1]Jones, J. C., Transactions Amer. Cer. Soc., Vol. IX, p. 528.

TABLE No. 2.

Result of Jones' Freezing Test.

Kind of Brick	Grade of Hardness.	Crushing Strength		No. Tested.	Per cent. loss in Strength.	Per cent. Pore Space.	Per cent. Absorption in 15 Minutes.	Remarks.
		Frozen.	Unfrozen.					
Soft-mud Surface Clay	Soft	1194	1374	1	13.1	33.0	83.0	Frozen Brick Scaled on face
	Med. soft	3567	3400	1	4.6	26.9	93.4	
	Med. hard	4289	5315	1	19.9	21.2	92.1	
	Hard	7377	7260	1	1.6	10.2	25.1	
Soft-mud Shale	Soft	2671	2913	3	8.6	26.2	52.9	1 brick Broken in freezing
	Med. soft	4625	5793	3	20.2	17.8	54.2	
	Med. hard	8522	10143	2	16.5	11.6	13.4	
	Hard	7606	11470	4	33.8	5.8	9.6	
Wire-cut Shale	Soft	3729	4637	4	19.6	27.6	40.0	2 bricks broken in freezing 2 cracked in freezing.
	Med. soft	6965	8117	4	14.2	17.1	33.9	
	Med. hard	9165	11315	4	19.4	2.1	34.5	
	Hard	115	11997	4	4.1	0.9	47.3	

Mr. Jones says, "As may be seen, there is little relation between the hardness of the brick and its resistance to frost. The surface clay suffered greatest loss when burned medium hard. The soft-mud shale suffered most when hard burned and the softest brick the least, while with the wire-cut shale brick, the soft and medium hard suffered most and the hard burned much less."

He also points out that there is little if any relation between the amount of pore-space and resistance to frost. This is in accordance with the work of Dr. Buckley[1] on building stones. Jones further says, "The rate of absorption does, however, seem to bear a much closer relation to the resistance to frost than do the other factors. This is true since the rate of absorption is governed by the same factor that controls the rate of flow through the pores, and consequently relief from danger of damage by frost." In conclusion he says, "It is of vital importance to consider the future position and condition in which brick are to be placed, in making tests to determine the ones best adapted. In situations where saturation is the controlling condition, as in foundations, the brick that contains the least pore space is best, but in places where the brick can drain, the one with large pore channels is best."

In further explanation it may be said that the degree of cohesion attainable in bodies made from strong plastic glacial and alluvial clays is very different from that obtained in weak sandy clays, or in shales. The former permit softening under the action of water, and a body of thoroughly mixed and thoroughly adhesive grains ensues. The shale does not soften to the same degree with water, and its comparatively coarse granules do not knit or assume as dense a body structure prior to burning. If burnt to the same degree, represented by an absorption of twelve or thirteen per cent. of water, the body made from the strong clay will probably defy frost, from its highly developed, but not too coarse, intercommunicating pore-system. The body made from a sandy or shale clay will probably be entirely unsafe from frost, on the other hand, because its composite grains, consisting of very fine particles, have perhaps hardened enough and become dense enough, but between the grains themselves, little or no bond has yet been developed, on account of their size and imperfect contact with each other. Their pore-system is coarse, the cavities large, and the elastic strength of the walls of the pore system is yet low. In other words, the structure consists of a mass of grains, themselves sufficiently vitrified to stand frost, but insecurely bound together as yet, and therefore not frost-proof.

The strong plastic clay-body will thus stand while the still granular shale-body will not. But if we now raise the temperature to a point where both clays are reduced to their minimum absorption, there is a very strong presumption that neither will fail from frost. Cer-

[1]Buckley, E. R. Quarrying Industry of Missouri, Mo. Geol. Surv. Vol. 2, Second Series, p. 45

tainly the shale will not, if it be of the type variety. The difference is that when the requisite heat was reached, the shale grains amalgamate and sinter together to a degree that the relatively coarser plastic clay can not equal, and it produces a dense vitrification, in which almost no water is admitted, and in which the factor of strength of the pore walls is very high. The condition of the plastic clay is meanwhile improved also as regards frost strength, though that was not needed, but as a rule it develops warping, sticking or other troubles in burning which make it impractical to use such heat in burning it.

One of the very strongest advocates of porous roofing tiles in America is the veteran tile maker, Mr. Charles Stolp of Chicago Heights, Illinois. He expresses his idea on the importance of adequate preparation of the clay as follows:

"A tile to be durable, though porous, must receive its strength from the preparation of the clay, and not depend on the burning to produce its weather resisting qualities."

One cannot study the methods of roofing tile manufacture in the old world without observing that they fully realize the importance of the above statement. They take superficial clays which have been weathering for centuries, and put them through a most exhaustive treatment of grinding and mixing, after which they still further prepare them by aging the clay in damp cellars for weeks before use. All of this tends to develop the cohesive strength of the clay.

Tiles made from clay thus prepared, though porous, will stand, and have stood, against the severe weather conditions of Sweden, northern Germany and northern Europe, and in this, our own country.

In this connection, the table on page 582 shows the absorption percentage of a number of brands of tiles which have been in use for long periods in this country with excellent results, will be interesting. In all cases, the samples were taken from roofs where they had done service, and the determinations were made by the writer for this purpose.

By reference to the table on page 582 it will be seen that sixteen different tiles were used in this test, representing eight different clays, as follows:

Three shales, three alluvial red-burning soft clays, one shale and alluvial clay mixed, and lastly, one No. 2 plastic fire clay.

It was thought that these samples would fairly well represent the field, not only as to kinds of material used, but in the variations in absolute absorptive capacity and duration of exposure in actual service on roofs.

Tiles A1 and A2 were hand-made, from a soft alluvial clay, and burned to a moderate degree of hardness. Each can be easily scratched with steel. The total absorption for 125 hours was 12.76% and 14.69% respectively. These tiles have seen 35 years service on a roof in north-central Ohio, but they show no signs of weakness or disintegration.

TABLE No. 3.

Showing the Water Absorptive Capacity of Various Roofing Tiles, in Percents.

Designation of Tile.	Duration of Immersion.							Per cent. gain of 1 hour over 15 min.	Per cent. gain of 125 hrs. over 15 min.	Remarks.
	15 Min.	1 Hour.	10 Hours.	24 Hours.	48 Hours.	72 Hours.	125 Hours.			
A1	9.63	11.82	12.08	12.08	12.13	12.27	12.76	22.74	32.50	Were in use 75 years.
A2	13.41	13.67	13.83	13.89	13.89	14.20	14.69	1.93	9.54	Made from a plastic clay.
B1	5.04	5.56	5.76	5.76	6.22	6.69	7.17	10.31	42.26	
B2	18.30	18.42	18.80	19.08	20.03	20.45	21.02	0.65	14.86	Were in use 92 years.
B3	6.09	7.63	7.75	7.75	8.43	8.80	9.06	25.29	48.76	Made from a plastic clay.
B4	18.46	18.80	18.96	19.63	20.63	21.13	21.46	1.84	16.25	
C1	11.11	11.83	12.86	13.20	13.72	13.89	14.06	0.64	26.55	Were in use 3 years.
C2	11.19	11.55	12.27	12.63	13.35	13.71	14.91	3.21	33.24	Made from a plastic clay.
D1	5.22	5.62	5.82	5.82	5.82	5.82	6.02	7.66	15.30	Were in use 4 years.
D2	1.63	2.61	3.26	3.26	3.26	3.43	3.49	60.10	114.11	Made from shale.
E1	4.24	5.50	5.61	5.78	5.92	6.36	6.86	29.71	61.79	Were in use 15 years. Made from a plastic clay and shale.
F1	0.24	0.24	0.24	0.62	0.80	0.99	1.44	0.00	500.00	Were in use 18 years.
F2	0.61	0.91	1.83	2.04	2.24	2.34	2.65	49.18	318.00	Made from shale.
G1	0.26	0.49	1.31	2.02	2.31	2.51	2.66	88.46	923.00	Were in use 35 years.
G2	0.47	0.70	1.14	1.40	1.73	1.93	2.26	46.80	380.80	Made from a plastic clay.
H1	1.26	3.05	7.31	7.57	7.61	7.61	7.74	134.12	514.20	Were in use 36 years. Made from No. 2 fire clay.

Tiles B1 to B4 inclusive were also made of a soft red-burning clay. It will be observed that there were two soft-burned tiles, and two medium-burned ones in this set. B1, for instance, took up 7.17% of water, while B4 absorbed 21.46%. It goes without saying that this

latter tile is very soft and easily cut by steel, while B1 is scratched with difficulty. Considering the length of time, 92 years, that these tiles were in use, and the high absorption of B2 and B4, it is quite significant that they should have remained in perfect condition.

Tiles C1 and C2 were made by modern machinery and modern methods, from a soft alluvial or semi-glacial clay. While the absorption in these tiles is high, nearly 15%, it should be said that their ability to withstand freezing and thawing is no doubt largely due to the thorough preparation given the clay, thus developing a high internal cohesive strength.

Tiles D1 and D2 were made from shale which had been ground and screened to 18 mesh, pugged in an ordinary pug mill, and then made directly into tiles. It will be noted that the absorption in these tiles is very much lower than in those described previously. While these two tiles have been in use four years in a northern climate, it is the writer's opinion that the one having an absorption of 6.02% is bordering very closely upon the point of failure from disintegration.

Tile E1 has been in use 15 years on a roof in central Ohio. The tile was made from a mixture of clay and shale, prepared by pugging in a pug-mill, and then forming into tile on a hand press. It will be seen that the per cent. of absorption is about midway between the tile made from shale and the average clay tile.

Tiles F1 and F2 were made from a shale. The latter was ground in a dry-pan, and then thoroughly pugged in a wet-pan before being formed into tile by power machinery. These tiles were both harder than steel; although they show an absorption in the one case of over 2½ per cent., they would fall into the class known as vitrified tiles. In fact tiles D1 and D2 are sold as vitrified tiles, but by noting the per cent. absorption it will be seen that they are a long way from being such.

While tiles F1 and F2 were used on a roof in Ohio for 18 years, they have recently been removed from the roof, not from any disintegration or failure of the tile, but on account of the roof leaking. The tiles were very poorly made, and were exceedingly crooked or warped from the extreme degree of vitrification to which they had been burned.

Tiles G1 and G2 were made from plastic clays. G1 was made from a red-burning soft clay, while G2 was made from a plastic buff-burning clay. It will be observed that the total percentage absorption is nearly the same in each tile, but the rate at which the absorption has taken place has been very much faster in the red tile than in the buff. Both tiles were harder than steel, and though in use for 35 years, are as perfect today as when made.

Tile H1 was made from a No. 2 plastic fire-clay, which, after being pugged, was made up by the hand-press method. While the absorption was 7.74 per cent., the tile has withstood the 36 years' use perfectly.

In this connection a paper by Wheeler[1], gives a similar table from his own observations in the field, which is here reproduced:

TABLE No. 4

Absorption of American Roofing Tile (Wheeler).

Designation of Tile.	Per cent. of Water Absorbed in					Remarks.
	¼ Hour.	1 Hour.	10 Hours.	24 Hours.	48 Hours.	
A	0.1 to 0.2	0.2 to 0.7	0.4 to 1.4	0.4 to 1.8	0.8 to 2.7	Very dark red, vitrified.
B	.....	0.1 to 3.2	0.1 to 3.6	0.3 to 3.7	0.3 to 3.8	Very dark red, vitrified.
B-1	.....	0.3 to 1.5	0.6 to 2.4	0.8 to 2.6	1.0 to 2.8	Dark gray, hard burnt.
C	12.0	12.0 to 12.2	12.5 to 12.6	12.7 to 12.8	13.2 to 13.4	Light red, burnt medium hard.
D	0.7	0.9	2.2	2.8	3.1	Dark red, hard burnt and glazed
E	5.4	5.6	5.7	5.9	6.0	Medium red, well burnt.
E-1	.....	5.3 to 5.8	5.5 to 6.3	5.5 to 6.3	5.6 to 6.4	Brown, hard burnt.
F	20.0	20.1	20.8	21.5	21.5	Light red, soft burnt.
G	4.0	4.7	5.5	6.0	6.4	Very dark red, hard burnt.
H	0.1	0.3	0.3	0.3	0.3	Very dark red, vitrified.
H-1	1.4 to 2.4	2.1 to 3.8	2.2 to 4.8	2.3 to 4.8	2.4 to 4.9	Dark red, hard burnt.
H-2	.....	6.7	6.8	7.1	7.2	Medium red.
H-3	6.5 to 6.8	6.5 to 6.8	6.9 to 7.1	6.9 to 7.1	7.1 to 7.4	Light red, soft burnt.
H-4	11.9 to 14.0	11.9 to 14.0	12.2 to 14.4	12.2 to 14.3	12.5 to 14.4	Very light red, very soft burnt.
H-5	8.4 to 8.7	8.4 to 8.7	8.5 to 8.8	8.5 to 8.8	8.6 to 8.9	Buff, medium burnt.

From the foregoing tables it can very clearly be seen that the percentage absorption of various weather resisting tiles has a very wide

[1]Wheeler, H. A. Trans. Amer. Cer. Soc., Vol. VIII, p. 154.

range, extending in table No. 3 from 1.44 to 21.46, a total difference of 20.04. The highest absorption among the shale tiles is seen to be 6.02 per cent., while the highest from plastic clay tiles was 21.46 per cent. The lowest absorption from shale tiles was 1.44 per cent., while the clay tiles gave 2.26 per cent. as the lowest amount.

From these figures and a study of the durability of the tile in question, it is evident that the percentage of absorption is in no way a measure of the durability of the tile, or its liability to disintegrate. It is quite possible that a microscopic study of the tile bodies would throw considerable light upon this question, and would perhaps give a better way of studying the ability of a tile body to resist freezing, than does the absorption test. The only value that can be attached to the absorption test is its measure of the increased strain or load put upon roof members by rains, or melting snow, which will be discussed a little later.

A second objection to porous tiles is that they become dirty and old-looking very shortly after laying. This is true in many instances especially in districts where much smoke and dust prevails. In cases where the rain water is desired for domestic use, this objection may become one of importance, but in many of our modern buildings it is in many cases desired to have the structure present an old or rustic appearance, in imitation of some ancient building. In such cases, the use of a porous tile has an advantage over the vitrified.

A third accusation against tiles of high porosity is their tendency to absorb large quantities of water during prolonged rains, and thus increase in weight to a degree prejudicial or even dangerous to the roof timbers. Referring to tables Nos. 3 and 4, the maximum absorption recorded in either set of tests is 21.50 per cent. Allowing, for the sake of argument, that every tile in a roof was able to absorb the maximum figure found, and that it was so situated as to have opportunity to become fully saturated, the increase in weight of the roof would not exceed 25 per cent. No roof should be constructed with a factor of safety so small that an overload of several times this amount would in the least endanger it. Similar loading from heavy snow-falls is common in all northern latitudes, and in many cases wind pressures amounting to more than 20 per cent. of the weight are common. Therefore, while an increase of weight from water absorption is an unquestionable fact, still it ought not to be a source of the least danger to a roof otherwise safe.

This argument is rather a "trade talking-point" than a real or serious accusation against soft-burnt tiles. No roofing tiles in use are apt to absorb as high as 20 per cent. Individual tiles may do so, but a whole roof of such tiles would be rare. Further, it is always unlikely that the tiles in a roof will be so situated that total absorption becomes possible. A roof covered with slowly melting snow may easily reach

60 or 80 per cent. of its total absorption, but no higher figures are probable, and while absorbing water on one side, it is usually evaporating it on the other.

The absorption test is more useful in this connection than as to frost resistance, however, and it should be made to note not only the total absorption of the tile, but the *rate* at which absorption takes place.

By reference again to table 3, it will be seen that a number of the tiles absorb from 70 to 90 per cent. of their total amount within the first fifteen minutes. Especially, the soft or very porous tiles, such as A2, B2 and B4, have, at the end of one hour, only increased their water content by less than 2 per cent. over what it was at the end of a fifteen minute immersion. These tiles would throw an increased load of 10 to 15 per cent. upon a roof, during a very short rain storm; while tiles like D2, F1, F2, G1, and G2, would pass through a long continued rain without materially increasing the load. The small increase taken up would be easy and gradual, thus throwing only gentle weight-changes upon the roof.

Manufacturing Conditions.—In the manufacture of the two kinds of tiles, the porous tile manufacturer should *make* his tile before it goes to the kiln, while the vitrified advocate depends on the burning to *make* his tile. In other words, the porous tile should receive much the greatest attention in the preparation of its raw material and in the forming, for if the tile is not strong and solid when dried, it will scarcely harden and strengthen enough in the firing process to make it frost proof. The vitrified tile may be made from granular, poorly-prepared raw material, but if it is of the right vitrifying properties, it may be made durable by hard burning.

Which tile is the more profitable to the manufacturer? The answer should be self-evident. The maker of porous tile, by spending great care in handling the crude, raw material, the working of which can be largely done by machinery, obtains a product which goes into the kiln in sound, straight condition. By stopping the burning at a point where the physical strength, though not at its maximum, is sufficient, he obtains a product which has not undergone severe volume changes, and therefore remains sound and straight and strong, but not brittle. His loss from overfired wares should be nothing, and his loss from warped or cracked or dunted wares should be very low, and his losses from handling, unequal kiln pressures, tilting, etc., should be at a minimum.

With the maker of vitrified tiles it is different. In the burning it becomes necessary to use some system of saggers as supporters for the ware, on account of the great shrinkage and consequent tendency to warpage, cracking, rolling of the ware in the kiln, resulting in wholesale deformation, etc. The handling and breaking of saggers or platform bricks

is an added expense; and in addition a large amount of heat is consumed in heating up this dead material each time. In some few cases, it is feasible to combine two kinds of ware, so that one will serve as the sagger and the other the contained charge, but this condition does not often obtain in roofing tile factories.

As it is desired to have the ware in all parts of the kiln vitrified, it often happens that ware nearest the fire will be overfired and ruined. Then large numbers of the tiles will warp and twist while under a vitrifying heat, no matter how carefully placed in setting, resulting in their loss, or in putting them in the second-class stock or cull. The percentage of good No. 1 wares brought from a kiln of vitrified tiles is very seldom 75 per cent. and the difficulty of disposing of the culls and seconds makes it necessary to assess on the first-class goods a large share of the total manufacturing cost.

Hence, it can easily be seen which manufacturer is spending the greatest amount of money to make his ware durable, when the losses of the two systems are taken into consideration.

If a manufacturer wishes to make use of shale clays, it would be more profitable to him to prepare his clay more thoroughly—that is, grind it extremely fine, temper it and allow it to age in bins until thoroughly disintegrated—it would then not be necessary for him to burn his product to such a high degree of vitrification in order to make it weather-resisting. The writer firmly believes that with shales properly tempered by grinding and aging, it would not be any more necessary to vitrify the ware than it is with tiles from the soft clays, and it is advantageous not to have the tile too vitreous. If it will absorb water up to about 5 per cent. of its dry weight, it will prevent sweating and dripping when laid on open construction.

PATENTS ON ROOFING TILES.

From the beginning of roofing tile manufacture on a commercial scale in this country, up to within the last decade, it was the general practice for plants to manufacture tiles whose shapes were patented as an invention, either their own, or some one else's operating under royalty.

In fact, from time to time large sums have been paid for patents of roofing tile designs, and in many cases the designs were found to be impractical for manufacture in a commercial way. In one instance known to the writer, $50,000.00 was allowed in stock for a patent on a tile design which was found to be be so expensive to manufacture that no one would use it, if free to do so. It certainly did not need a patent to protect it from infringement. Many of the older companies, that have in the past held patents, have allowed them to run out without effort to obtain modifications which would keep the patent alive.

The time has come, in the manufacture of roofing tiles in this country, that no single design is going to find universal acceptance

or control the market. There are enough unpatented designs of tiles of perfectly commercial grade, in all styles, so that no one should think that a new patent design will protect him from competition. Today, it is a question of producing tiles of the proper quality at the proper price.

As a matter of general interest to roofing tile makers, present and prospective, it has been thought worth while to record in this volume some statistics as to just what has been done in the way of patents on roofing tiles in this country. The data have been compiled from a study of the records of the United States Patent Office. It is needless to say that only a very small per cent. of the patents taken out have ever been followed by actual manufacture of tiles according to the patented design.

Listing these roofing tile patents according to their distribution in the states from which they originated, the order is as follows, including all patents prior to 1909:

TABLE No. 5

Patents Granted for Roofing Tile Designs, Originating in the United States.

State	No.	State	No.
Ohio	30	Kentucky	2
Illinois	19	California	1
Maryland	12	Colorado	1
New Jersey	10	Connecticut	1
New York	10	Kansas	1
Pennsylvania	8	Minnesota	1
Indiana	8	North Carolina	1
Missouri	8	New Hampshire	1
Massachusetts	4	Oregon	1
Iowa	3	Tennessee	1
Michigan	3	Texas	1
Florida	2	Vermont	1
Mississippi	2	West Virginia	1
Georgia	1		
		Total	122

TABLE No. 6

Patents Granted in the United States, for Roofing Tile Designs Originating in Foreign Countries.

Country	No.
Germany	22
England	5
France	3
Denmark	1
Hungary	1
Sumatra	1
Sweden	1
Total	34

Observing the above table it may be plainly seen in what sections of the country the greatest interest and activity has existed in roofing tile manufacture and use. Ohio outranks any other state in the number of patents taken out, as it always has in the number of roofing tile plants. It will also be noted that the southern and western states, which climatically are perhaps best suited to the use of cheap forms of tile, fall far behind. It is only very recently that there have been any roofing tile plants in these states.

Among the foreign countries, Germany leads with over three times as many patents as any other country, while France, one of the greatest tile using centers in the world, has taken out but three patents in this country.

The first patent for a roofing tile design was taken out in this country by J. Parker, August 15, 1835. The tiles were of a form resembling brick, or possibly more like the promenade tile or quarries of today. No provision was made for the tiles to overlap or to lock, hence it must have been the intention to bed them in clay or cement, making to all intents a pavement of the roof, very much as the Chinese do at the present time.

The next patent was was taken out in December, 1855, by C. Graessle. This tile was of the interlocking type. One-half of the tile was made in a low half-round; the other half, consisting of the pan of tile, was flat. It was protected on the edge by two parallel ribs, with a gutter between for the tongue of the adjacent tile. That is, the half-round of one tile acted as a cover for the locks on its neighbor. The upper end of the tile carried a lug or projection on the under side, by which the tile could be hung on the roof purlins. On the top side of the upper end of the tile were two cross ribs to form the head-lock, while the lower end of the tile was provided with two counter tongues. Thus it can be seen that a good interlocking tile was devised and the principles of interlocking understood in this country as far back as 1855.

In April, 1858, J. S. Graessle obtained a patent on an interlocking tile of very good design. In fact it is superior to many designs on which patents have been granted since. The tile is constructed with a double locking device on all four sides, and has a broad flat pan for conveying the water.

The first patent on an interlocking shingle tile was taken out in 1867, by Wm. Cranage, of Cleveland, Ohio. The idea in this patent was that of making the tile as though it were composed of two separate parallel plane surfaces of the same size and thickness, of which the upper one had been shifted so that it no longer covered the lower exactly, but left a side and end of the lower plane exposed for a half-inch or so wide, thus making provision for overlapping. This tile would make a very uninteresting roof in any case, for the method of overlapping the edges by extensions of half-tile thickness produced a perfectly plane surface from tile to tile in the same tier, and the only relief was that due to overlap of one tier on another. The vertical lines would thus be lost almost at once, and only the horizontal would be visible, even near by, thus accentuating the characteristic fault of this kind of tile unnecessarily.

The true interlocking shingle tile, having side and end-locks of the regular tongue and groove pattern, did not appear until 1874, when Louis Hamel, of Baltimore, obtained a patent on such a design.

The first patent covering a normal or Spanish tile was obtained in 1873, by Daniel Swain, of Dover, New Hampshire. His plan provided for the use of two patterns, one of which was a broad, concave tile, made flat on the under side, to allow it to sit down flat on the sheathing boards. Rows of these broad tiles were carried up the roof in close parallel lines, allowing each upper tile to overlap the next lower as usual. To cover the joints between the edges of the parallel rows, small half-round tiles were used.

During 1886, three patents were granted for Spanish or roll tiles, with the pan and roll combined in one piece. The first of these was taken out in July, by Albert Aldrich, of New York. His design, however, was impractical to manufacture, on account of the locks requiring undercuts, which cannot be made by ordinary pressing machines. A much better pattern, and entirely practicable to make, was patented by Edwin Bennett, of Baltimore, during the latter part of the same year.

The first patent on a tile design to be run out in bar form on an auger machine and subsequently cut into appropriate lengths was taken out in 1889, by Joseph Repp, of Akron, Ohio. This tile, instead of having a roll or rounded elevation on its face, was made with an angular ridge or inverted letter V, with a pan and a single side-rib. This design was entirely practical commercially, and was manufactured for some

time. This design is of interest chiefly because it was the forerunner of the numerous patterns of auger-machine Spanish or S tiles that have followed.

The first auger-machine interlocking tile to be patented in this country was that of C. Jungst, of Germany, during the year 1887. His tiles are provided with side-locks only, the end-locks being formed by the upper and lower ends of two contiguous tiles overlapping, like ordinary shingle or S tiles.

The largest number of patents on roofing tile designs taken out in any single year was in 1890, when twelve were granted.

The number of patents taken out annually from 1890 dropped off until 1903, when it increased to ten for the single year.

During 1908, there were seven patents taken out, but they were nearly all for cement tiles. For the benefit of those who may be interested in looking up the literature of tile patents more carefully, the following list of patents granted up to February, 1909, has been prepared:

TABLE No. 7.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue.		Name of Grantee.	Number of Patent.	Remarks on Style of Design.
Year.	Month and Day.			
1835	Aug. 15	J. Parker	not giv.	Flat or pavement tile.
1855	Dec. 11	C. Graessle	13,906	Interlocking.
1858	April 27	J. S. Graessle	20,059	Interlocking of fairly good design.
1862	May 6	Samuel M. Logan Philo E. Baker	35,164	Pan tile.
1862	Aug. 19	Isaac Marsh, Jr. Griggs Marsh	36,225	Quarry tile for roofs.
1867	Nov. 12	George Cook	70,805	Improved pan tile.
1867	Dec. 3	William Cranage	71,583	Flat or shingle tile.
1867	Dec. 10	Orville Manly	72,060	Quarry tile to be laid in coal tar and clay.
1870	Oct. 4	William Utley	108,068	Flat or shingle tile, very little change over 71,583
1871	Feb. 21	Charles Howard	111,938	Interlocking tile, poor locks
1871	Dec. 5	John B. Hughes	121,624	Improved pan tile, like 70,805.
1872	July 23	Isaac Hodgson William H. Brown	129,826	Improvement on tile or glass roofs.
1872	Aug. 6	Alexis Roux Pierre Roux	130,156	Interlocking tile with good locks.
1873	Aug. 19	Daniel Swain	142,056	Spanish or normal tile, too heavy.
1874	Feb. 3	Sanford S. Perry	147,018	Improved pan or Roman tile.
1874	Feb. 3	Garry Manvel	147,061	Overlapping or interlocking tile of poor design.
1874	April 7	John F. Graessle	149,469	Diamond tile.
1874	May 5	John T. Weybrecht	150,642	Interlocking tile of French design.
1874	July 14	Louis Hamel	152,991	Interlocking shingle tile, locks good.

TABLE No. 7—Continued.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue.		Name of Grantee.	Number of Patent.	Remarks on Style of Design
Year.	Month and Day.			
1874	Sept. 8	Edwin Bennett	154,828	Diamond tile.
1874	Dec. 1	Louis Hamel	157,392	Interlocking quarry tile.
1875	Mar. 2	John M. Lewis	160,445	Interlocking tile of poor design, requires two forms of tile.
1875	Mar. 30	Samuel Mills	161,538	Diamond tile.
1875	May 4	Garry Manvel	162,836	Overlapping or interlocking tile of poor design.
1875	June 8	La Fayette Parker	164,203	Diamond tile.
1875	Nov. 30	Calvin T. Merrill	170,582	Diamond tile.
1876	Feb. 22	Jonas Smith	174,021	Diamond tile, two piece.
1876	Mar. 28	Cyrus M. Warren	175,533	Cement shingle tile.
1876	Aug. 29	Jacob Greenawalt	181,670	Diamond tile, slightly modified.
1876	Dec. 26	George Elberg	185,632	Diamond tile modified.
1877	June 26	Philip Pointon	192,451	Diamond tile.
1877	Sept. 25	John W. Hoyt	195,607	Metal tile filled with cement, would be impractical.
1877	Nov. 6	Hiram Stripe	196,773	Improved pan tile, side lock.
1877	Dec. 18	Philip Pointon	198,414	Interlocking tile, poor locks
1878	April 30	Henry E. Merrill	202,953	Diamond tile.
1879	Feb. 4	George A. Taylor	211,944	Pan tile.
1879	Feb. 4	Edwin Bennett	211,955	Improved diamond tile.
1879	Aug. 26	Frank Waters	219,044	Interlocking tile, poor design.
1881	Mar. 15	John J. Williams	239,007	Improved quarry tile.
1881	Mar. 22	Lorenzo Lane Laurin D. Woodworth	239,104	Diamond tile.
1881	Sept. 27	William Barry	247,596	Flat tile with side lock, poor.
1882	Feb. 7	Thomas B. Atterbury	253,174	Improved shingle tile, not good.
1882	Nov. 21	Lorenzo Lane Laurin B. Woodworth	267,904	Diamond tile, improved over 239,104.
1883	Mar. 20	Christopher McCarthy James P. Cumming	274,354	Interlocking quarry or flat tile, impractical.
1883	Aug. 14	Wilhelm Ludowici	283,126	Interlocking tile of good design.
1885	May 5	Fawcett Plumb	317,414	Flat shingle tile, method of fastening.
1885	June 23	Paul Simons	320,822	Diamond tile, hollow.
1885	July 28	John E. Donaldson	322,917	Interlocking flat shingle, would be too expensive to manufacture.
1886	April 27	Frank Hengesbach	340,668	Interlocking.
1886	July 13	Carl Weise	345,400	Improved flat or shingle tile.
1886	July 20	Elbert Aldrich	345,942	Spanish tile.
1886	Aug. 17	Henry Hall	347,425	Facing or siding tile.
1886	Sept. 7	John C. Litzelle	348,920	Holland pan tile, resembles Spanish tile.
1886	Nov. 2	Edwin Bennett	351,956	Spanish tile.
1887	April 19	E. C. Lindemann	361,425	Spanish tile composed of two members.

TABLE No. 7—Continued.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue. Year.	Month and Day.	Name of Grantee.	Number of Patent.	Remarks on Style of Design.
1887	Aug. 2	Carl Jungst.....	367,758	Auger made interlocking tile, suitable for cheap structures only.
1887	Aug. 16	John E. Donaldson .	368,386	Interlocking tile, poor locks.
1888	Feb. 7	Edward Walsh, Jr...	377,588	Combined pan and roll tile of glass.
1888	April 10	Arthur W. Cooper ..	380,864	Combination shingle tile and metal roof, not practical.
1888	July 3	Albert Diedrich	385,343	Interlocking flat tile or quarries.
1889	May 21	John Erec Gusten .. / Carl Wm. Braun ...	403,837	Diamond tile.
1889	Sept. 17	Joseph Repp	411,299	Improved auger made tile, the forerunner of the modern Spanish.
1889	Sept. 24	Robert Liddell	411,666	A combination flat and cover or joint tile, not commercial.
1890	Feb. 18	E. C. Lindemann....	421,734	Improved shingle tile.
1890	April 22	E. C. Lindemann....	426,289	Roman or pan tile.
1890	April 29	John E. Donaldson .	426,584	Interlocking tile, very poor locks.
1890	June 17	George H. Babcock..	430,362	Ornamental diamond or scale tile.
1890	June 17	George H. Babcock..	430,363	Improved shingle tile.
1890	June 17	George H. Babcock..	430,364	Scale or modified diamond tile.
1890	June 17	George H. Babcock..	430,365	Eave tile or starters.
1890	June 17	George H. Babcock..	430,366	Interlocking tile known as "Conosera."
1890	June 17	George H. Babcock..	430,367	Hip tile.
1890	June 17	George H. Babcock..	430,369	Gable tile.
1890	June 17	George H. Babcock..	430,371	Corner or mitre tile.
1890	Oct. 14	E. C. Lindemann....	438,321	Interlocking Spanish tile.
1891	Mar. 31	Edwin Bennett	449,397	Pan and cover tile.
1891	Dec. 15	John E. Donaldson / Edward C. Elder ..	465,364	Interlocking tile, locks too shallow.
1892	Jan. 26	Basil Edwards	467,791	Improvement on shingle tile.
1892	June 21	Joseph Martin Wood	477,346	Interlocking tile with method of fastening.
1892	July 5	Joseph Repp	478,171	Improved auger made Spanish tile.
1892	July 26	Frederick N. Marvick / John Walter	479,441	Overlapping flat tile.
1892	July 26	Frederick N. Marvick	479,442	Interlocking tile.
1892	Sept. 27	Henri Sturm.....	483,180	Interlocking hollow tile.
1893	Feb. 14	C. W. E. Wutke.....	491,625	Interlocking tile.
1893	May 9	Francis Andrew	497,161	Interlocking tile.
1893	Aug. 8	Max Kaestner	502,725	Diamond tile.
1893	Dec. 26	Andrew M.Cheeseman	511,506	Pan and roll tile combined.
1893	Dec. 26	Andrew M.Cheeseman	511,507	Pan and roll tile combined.
1893	Dec. 26	Andrew M.Cheeseman	511,683	Pan and roll tile, two piece.

TABLE No. 7—Continued.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue.		Name of Grantee.	Number of Patent.	Remarks on Style of Design.
Year.	Month and Day.			
1894	Jan. 23	Wilhelm Ludowici	513,430	Interlocking tile.
1894	April 10	George H. Babcock	517,832	Tower tile.
1894	April 17	John Veen F. A. Dornberg	518,294	Interlocking tile.
1894	July 10	John E. Donaldson John Athern	522,686	Interlocking tile.
1894	July 10	Samuel K. Cohen	522,879	Spanish tile.
1894	July 24	Albert Kayser	523,353	Interlocking tile of French pattern.
1894	Oct. 16	Christian Lesmeister	527,431	Interlocking tile.
1894	Dec. 4	H. Niederlaender	530,119	Interlocking tile.
1895	Mar. 5	Thos. A. Aldridge	535,183	Interlocking shingle tile.
1895	April 16	Karl Thomann	537,732	Interlocking tile.
1895	Aug. 13	Michael Hoffelt Matt Hoffelt	544,303	Interlocking tile, poor locks
1895	Aug. 20	Lucian F. Plympton	544,770	Pan and cover tile, two pieces.
1896	Jan. 21	George A. Taylor	553,321	Pan tile.
1896	Feb. 11	Clinton Keiser	554,274	Interlocking flat tile.
1896	April 14	Gustav Krebs Abraham Weil	558,395	Diamond tile.
1896	June 30	Heinrich Brocker	562,798	Diamond tile.
1896	Aug. 4	Patrick F. Jones	565,356	Spanish tile.
1896	Dec. 15	Milo Horlocker	573,328	Interlocking tile.
1896	Dec. 29	Wm. A. C. Waller	573,939	Diamond tile.
1897	Mar. 23	Charles T. Harris	579,481	Shingle tile.
1897	Oct. 26	John J. Merrill	592,474	Interlocking tile.
1898	Feb. 22	Marshall C. Barber	599,312	Spanish tile.
1898	April 26	Abraham Weil	602,889	Diamond tile.
1898	May 17	Jacob Freund	604,035	Improved auger made Spanish tile.
1898	June 14	Gustav Schulze	605,654	Diamond tile.
1898	June 14	Christian W. Schou	605,750	Shingle tile with metal locks.
1898	July 19	Henry B. Skeele	607,489	Interlocking Spanish tile.
1899	Jan. 24	Wilhelm Borgolte	618,197	Diamond tile.
1899	July 11	Emil Ahrens	628,737	Diamond tile.
1899	Sept. 12	Hendrick Ludeling	633,019	Hollow interlocking tile.
1899	Dec. 12	John E. Donaldson	638,802	Small interlocking tile.
1900	Jan. 2	William D. Turnley	640,338	Glass tile and method of fastening.
1900	May 29	Leopold Gnoth	650,387	Interlocking tile, side locks only.
1900	June 5	Gustav F. Kasch	650,939	Auger made pan tile.
1900	June 19	Wilhelm Ludowici	651,873	Interlocking tile similar to the Spanish.
1900	July 31	Nicholas Daubach	654,717	Tile similar to Spanish in connection with a metal-cement joint.
1901	Jan. 14	John W. Carnes	691,239	Interlocking tile, poor design.
1901	Dec. 10	George P. Heinz	688,641	End locks for tile.
1902	June 10	Albert Gustorp	702,202	Diamond tile.

TABLE No. 7—Continued.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue.		Name of Grantee.	Number of Patent.	Remarks on Style of Design.
Year.	Month and Day.			
1902	Sept. 2	Holden Brock.....	708,307	Interlocking tile, no head lock.
1903	Jan. 13	William C. Sharp... John C. Sharp	718,284	Improved shingle tile.
1903	Jan. 27	Frank E. Coombs ...	719,193	Lock for interlocking or Spanish tile.
1903	Feb. 3	Joseph Schall	719,514	Spanish tile, interlocking.
1903	Feb. 17	Jons Nilsson Mauntin	720,831	Corrugated tile made interlocking by means of metal strips.
1903	Mar. 17	Henry B. Skeele	722,918	Spanish tile, interlocking.
1903	June 2	Abraham B. Klay ..	730,131	Interlocking tile.
1903	July 28	Jacob Simmerman...	734,976	Improved shingle tile of glass or clay.
1903	Aug. 18	Johannes Veen.....	736,801	Auger made pan tile.
1903	Sept. 15	Henry Ohaus	739,211	Improved shingle tile.
1903	Dec. 15	Carl Schlachter	746,747	Interlocking corrugated or Spanish tile.
1903	Dec. 29	George C. Zwerk	748,141	Shingle tile to be made of cement and metal.
1904	Jan. 12	Walter P. Grath	749,182	Interlocking Spanish tile.
1904	Feb. 23	Henry Baden ..... William Gluss	753,188	Diamond tile.
1904	Oct. 18	Wilhelm Ludowici...	772,363	Interlocking tile, two parts
1904	Oct. 25	Carl Theo Seested ...	773,230	Interlocking tile, with method of fastening, intended to be made of cement, no end locks.
1904	Dec. 6	Walter C. Mitchell...	777,058	Mission tile, two pieces.
1905	April 18	Leslie G. Sharp	787,474	Interlocking Spanish tile.
1905	April 18	Leslie G. Sharp	787,475	Modified shingle tile, to be press made.
1905	May 2	Leslie G. Sharp	788,676	Modified shingle tile, to be press made.
1905	Sept. 12	James H. Perrin	799,259	Diamond tile, two parts.
1905	Oct. 10	Wenzel E. Miksch ..	801,736	Interlocking tile, auger made, no head locks, partly hollow.
1905	Oct. 31	Ludwig J. W. Birn ..	803,524	Interlocking tile, modified "Conosera."
1905	Nov. 14	Henry Meyer	804,754	Diamond tile preferably of cement and metal.
1905	Nov. 28	Lloyd G. Satterlee...	805,884	Modified shingle tile.
1906	Mar. 13	Frederick M. Lensch	814,970	Overlapping corrugated tile, no end lock, preferably made of cement and metal.
1906	Mar. 27	Orvey Price	816,252	Shingle tile, of cement and metal.
1906	April 17	Henry Baden	818,333	Diamond tile.
1907	Feb. 19	Edward E. Johnston.	844,453	Interlocking tile.
1907	Feb. 26	Edward H. Binns ...	845,290	Shingle tile made of strawboard, lime or sand, metal and asphalt.

TABLE No. 7—Concluded.

Consecutive List of American and Foreign Roofing Tile Patents.

Date of Issue. Year.	Month and Day.	Name of Grantee.	Number of Patent.	Remarks on Style of Design.
1907	Mar. 26	Charles C. Davis	848,537	Shingle tile of cement and metal.
1907	April 30	Albert Voigt.....	852,402	Diamond tile.
1907	May 7	Edward Coffin	853,063	Diamond tile.
1907	July 23	Ignatz H. Freund ...	860,796	Shingle tile with glass opening preferably of cement, metal and glass.
1908	Feb. 25	Bertel R. Christensen	880,012	Pan and roll, cover tile.
1908	Mar. 10	Edward T. Winslow..	881,522	Corrugated or angle tile in combination with angle covers for the side joints
1908	Mar. 24	Michael Marte	882,765	Shingle tile having an embedded metal hook for hanging the tile. Very impracticable, metal would be destroyed in the burning.
1908	April 21	Carlos N. Bruzand...	885,663	Interlocking tile.
1908	June 2	Joseph Freund	886,595	Interlocking tile, locks imperfect.
1908	July 7	Isham P. Walker....	892,917	Pan tile with separate cover tile.
1908	July 28	Joseph W. Farr	894,489	Cement-metal sheets for roofing, no particular style.
1908	Nov. 10	Samuel A. Jones	903,477	Diamond tile.
1908	Dec. 29	Fred Lotulip.....	907,824	Modified shingle tile, impracticable to make on account of under cuts.
1909	Feb. 9	Emery P. Auger	912,057	Cement shingle tile.
1909	Feb. 16	Byron L. Bacot	912,353	Spanish tile, having an impractical lug on the under side.

Other Patents Pertaining to Tiles or Tile Roofs.

1890	July 15	John E. Donaldson ..	432,122	Die for forming roofing tile.
1891	Aug. 25	E. C. Lindemann....	11,186	Reissue of patent 361,425, Spanish tile.
1891	Dec. 8	Mark A. Jackson .. / John H. Jackson ...	464,503	Roofing tile fastener, for shingle tile.
1901	Mar. 26	G. A. Nebling.....	670,723	Means for rendering interlocking tile roofs weather proof.
1903	Feb. 24	Henry B. Skeele	721,246	Metal fastener for tile.

As stated before, the day of patented tile designs has nearly passed. The possible variations in the shapes, locks, and mode of attachment of the three fundamental varieties have been pretty thoroughly exploited, and the possibility of a new design being brought out, which could play a new variation of this well worn theme, and still have any real advantage in it over those which have been long since used, is now quite remote. We may fairly say that the roofing tile designs are now pretty well crystallized into a few types. What is needed at present is more tile plants to use these standard patterns in manufacturing tiles of first class color and strength. No one needs a patented design now to compete in the roofing tile business.

CHAPTER III.

THE SELECTION OF CLAYS FOR ROOFING TILE MANUFACTURE.

In the selection of a clay for the manufacture of roofing tile, the qualifications which should be most carefully considered are plasticity, strength, shrinkage, burning behavior and fusibility, color, hardness and porosity.

In a careful search of ceramic literature, no data have been found bearing directly on the testing of clays for roofing tile purposes. In order to give as clearly and as exactly as possible just what the qualifications of a clay should be to make it suitable for roofing tile manufacture, it was thought best in the absence of any previous work, or any kind of recognized standards to go by, to make a thorough study of such clays as are or have been used for successful roofing tile industries, and let the data thus obtained serve as a basis for future judgments as to the fitness of clays for this purpose.

There were in the country in the summer of 1908 fourteen such plants. There were several others which had manufactured roofing tile on a commercial scale at one time, but which had for one reason or another gone out of the business. Samples were obtained from nearly all of the active plants and from some of the defunct ones. Owing to sensitiveness on the part of some of the manufacturers, as to tests of their clay being published, these samples are all listed in the following tables by letters instead of names, so that the source of the samples cannot be established from anything which appears in the report.

For the benefit of interested readers, it may be said that all of the clays of which tests are published herewith were taken either from plants in active operation or recently defunct, and that of the active plants samples were obtained from all but a very few. In one or two instances, the objections of the management to having their clays studied could not be overcome. The list of clays studied, however, is strictly representative of the materials used in roofing tile manufacture in this country. Every type of clay which is used in any past or present plant is represented by one or more samples. In one case, the tile body is made of a mixture of three separate clays and a sample of each clay was taken and tested separately, and another sample of the mixture as a whole.

The samples, with two exceptions, were taken either from the unground clay in the stock shed, or from the ground clay which had

passed the dry-pan, it being desired to obtain the samples unaffected by any tempering operation. In the two exceptional cases, the clays were collected at the end of the pug-mill or tempering machine. As all of these samples were naturally soft plastic clays, it is believed that the tempering has produced but very little difference, and that after drying out and regrinding, they would compare closely with samples taken direct in the pit.

Taking up the various properties of clays, it is deemed best to discuss the bearing that each has on the value of the clay before considering the actual test as carried out.

Plasticity.—Plasticity in clay is the property which it possesses, when mixed with water, of being moulded into desired shapes and of retaining its shape after moulding. It is not necessary to here go into the cause of plasticity, for which a number of theories have been advanced, none of which have been fully accepted, nor have any practical methods been devised for the measurement of this valuable property of clays.

Among practical clay workers, such terms as plastic, very plastic, poorly plastic, or medium plastic are used. Fine grained plastic clays are known as "fat," while sandy or coarse grained ones are termed "lean."

The amount of water required to develop the plasticity of a clay is to a certain degree a measure of its plasticity. The finer the grain of the clay, the more water is required to develop its plasticity. In ball clays, for instance, as high as 30 or 40 per cent. of water may be required to get the best plasticity, while some shales will only need from 15 to 25 per cent.

The samples of roofing tile clays as described above were tested as to the amount of water required by each for plasticity. It was not possible to tell when the different samples reached the same degree of plasticity by any other test than the ordinary sense of feel. When tempered to a point where they felt right for manufacture, the amount of water was determined accurately, with the following results:

TABLE No. 8.

Showing Per Cents. of Water Added to Develop Working Plasticity in the Standard Roofing Tile Clays.

Designation of clay.	Percentage of free water contained	Designation of clay.	Percentage of free water contained.	Designation of clay.	Percentage of free water contained.
A	18.31	F	20.65	K	18.97
B	15.22	G	13.82	L	17.21
C	22.22	H	21.22	M	15.86
D	20.35	I	15.99	N	16.13
E	19.16	J	20.83	O	18.74

From table No. 8 it will be seen that Sample G is the only one that requires less than 15 per cent., while none of them reach very high figures. Sample C, with 22.22 per cent., is the highest. The average of all the samples is 18.31 per cent., which is about the same as shown by clays used in stiff-mud brick industry and similar processes.

By reference to table 8 it will be seen that in a general way the clays requiring the larger amounts of water to develop plasticity are also the ones that develop the highest drying shrinkage which would indicate a connection between the degree of plasticity, the water used in tempering, and the shrinkage in drying. Clays for roofing tile manufacture should have a moderate degree of plasticity—sufficient to permit of their being easily worked, or moulded into the desired shapes, but excessive plasticity is dangerous, in that it indicates a similar excess in air shrinkage and the other drying qualities of clays and excessive lamination of the clay in manufacture. Clays with the highest degree of plasticity are the ones most likely to crack in drying. Then, too, the excess water that must be used in tempering extremely plastic clays causes increased expense in drying, as well as being more apt to dissolve soluble salts and bring them to the surface of the ware as a scum or whitewash. The tempering water is frequently highly impregnated with soluble salts, hence the use of less water in tempering the less plastic clays is an advantage.

Strength.—The strength which a clay develops on drying is very important to the roofing tile manufacturer. His ware, for the greater part, is of thin cross section, and unless the clay has a fairly good strength, large losses will result in handling the ware during the setting, and still greater losses will occur if the ware is set without saggers, or some form of kiln supports, as roofing tiles are being set at the present time in several of the plants. In other words, the clay should possess strength enough to resist the crushing strain of the superimposed tile, in such modes of setting as are otherwise most economical. It is not known that all the factors influencing the strength of a raw dry clay are definitely determined, but some at least of these factors may be recognized.

Upon evaporating from a clay, the water previously added to produce plasticity, the clay particles are drawn closely together, and the grains develop a cohesion between each other. By some, this strength is thought to be due to an interlocking of the clay grains, while others contend that it is due to the cementing power of colloidal matter developed by the action of water on clay particles.

The strength is usually measured by the so-called tensile test using a small brickette, having a central cross section of one inch square, and widened ends which are caught in the jaws of clamps. An increasing load is very carefully applied, breaking the brickette at the narrower part by a steady pull. For some purposes, this test will

probably answer, but in testing a clay for roofing tile purposes it was thought that the cross breaking strength would give data nearer to the actual conditions to which such clays are exposed in practice. The following test was devised for this purpose:

The trial pieces were made from the standard roofing tile clays, all of which had previously been carefully ground and screened to pass a 20-mesh screen, this size being commonly used commercially. The clays were then mixed with water by hand upon a clean table, until each clay had been made a little softer than was considered its proper working condition. Each clay was then made into a large ball-shaped lump, containing from 30 to 50 pounds. These balls of clay were wrapped in wet burlap and packed in damp boxes, made of plaster of Paris. The clay was allowed to remain in the damp boxes for at least 48 hours, when each in turn was removed, placed on a wedging block and thoroughly reworked. It was found that in nearly every instance the clay had assumed a nice condition; that is, the water added for plasticity had become evenly distributed, and the clays had mellowed or toughened to a very marked degree.

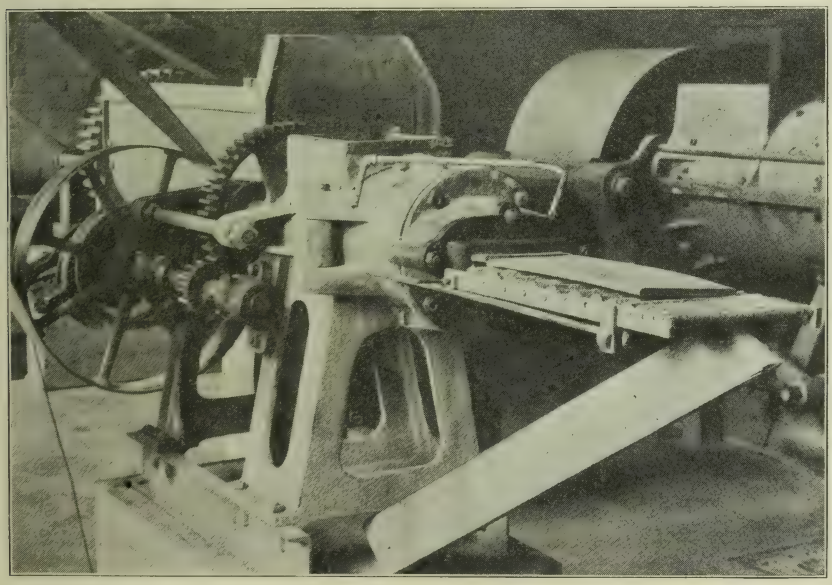

Fig. 19—Mueller Auger Machine.

The trial pieces for the cross breaking tests were made by running the different clays through a small auger-machine made by Mueller Bros., St. Louis, Missouri, shown in the above illustration.

The bar was approximately one-half inch thick by six inches wide, and this was cut into fourteen-inch lengths. Each tile was then carefully cut lengthwise in the center, producing two strips three inches

by fourteen inches by one-half inch. These were placed on boards to dry in an open room at ordinary room temperature, up until the time of testing, when they were placed in a drying oven, and heated to 212° Fahrenheit for 24 hours, being removed from the dryer a few at a time as needed for testing. They were first allowed to cool to about atmospheric temperature. In most of the clays, eight trial pieces were used to make this test, while ten were used in a few.

The object in using the auger-machine to make the trial pieces was to eliminate the personal factor in moulding as much as possible. In addition, the bar of clay was thus made under actual working conditions and in the full size, though subsequently cut up. The trial pieces were carefully measured by calipers having a Vernier scale, correct to the second decimal place. The thickness and width of each bar was thus taken.

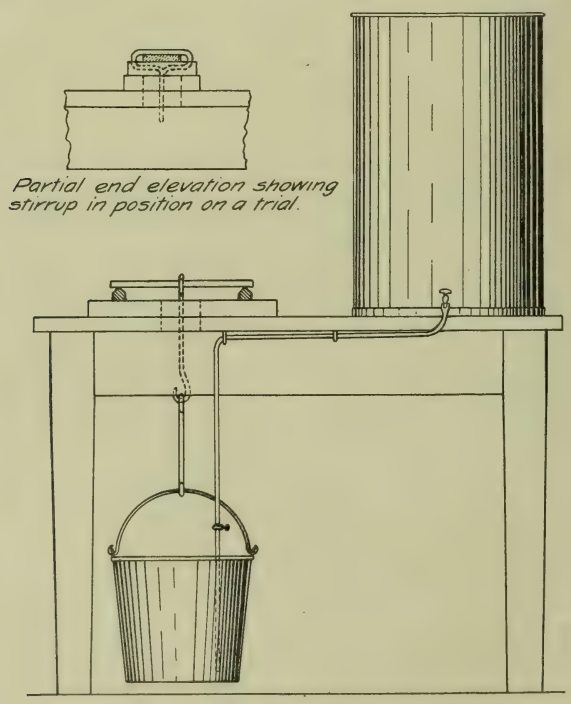

Fig. 20—Cross-Breaking Machine.

The actual test of breaking the trials was accomplished by the use of the apparatus shown in Figure 20. It will be observed from the cut that the test piece to be broken was supported upon knife edges, made of hard oak, and placed ten inches apart from center to center. A stirrup having a knife edge resting on the bar of clay, and a hook at its lower end, was placed midway between the end supports. A pail or bucket was then attached to the hook as shown. The actual breaking

load or weight was supplied by water from the tank on the table. A small rubber tube was used to convey the water from the tank to within an inch or so of the pail bottom as shown. Attached to the rubber hose was a pinch-cock, which was closed the instant sufficient water had been run into the pail to break the piece. By keeping the hand upon the pinch-cock constantly, it was possible to shut off the supply almost instantly, or at least with only a small factor of error.

After each breaking test, the pail and its contents was carefully weighed, the water returned to the supply tank, and the operation repeated.

Each breaking weight has been calculated into load per square inch in the following table:

TABLE No. 9.

Results of the Cross-breaking Test as Applied to the Standard Roofing Tile Clays. Bars One-half Inch by Three Inches in Cross Section.

Designation of clay sample.	Load in pounds per square inch.	Designation of clay sample.	Load in pounds per square inch.
A	6.33	H	11.50
B	6.41	I	6.98
C	5.95	J	8.78
D	4.17	K	7.04
E	7.53	L	not determ'ed
F	5.04	M	4.79
G	2.76	N	9.05
		O	not determ'ed

From the table it will be noted that clay H stood the greatest load, 11.50 pounds, while clay G was the lowest, only requiring 2.76 pounds to break it. Clay G was extremely brittle or short, and was very hard to handle without breaking. Clay D, while much better, was still too weak. Care would have to be exercised in working with it. Those clays having a cross-breaking strength of 5 pounds or more per square inch were all safe to work with. Clay H would stand very rough handling in setting, but this advantage is offset by having a higher shrinkage than the other clays.

Clays of the type of A, B, C and F are good commercial clays, in so far as strength of the unburned, dried ware is concerned.

Figure 21 is a graphic representation of the necessary loads to break the various trials.

Air Shrinkage.—The volume changes of clays are preferably studied in two stages, proceeding from dissimilar causes; viz., the drying or air shrinkage and the burning shrinkage, Only the former will be considered here.

The water which is added to a clay to make it plastic is lost by evaporation, causing a loss of volume. The loss of volume or shrinkage

varies greatly with different clays, and with the same clay under different modes of treatment. The amount that a clay will shrink in drying is best expressed in per cents. of the initial length as linear shrinkage, or of the initial volume as cubic or volume shrinkage.

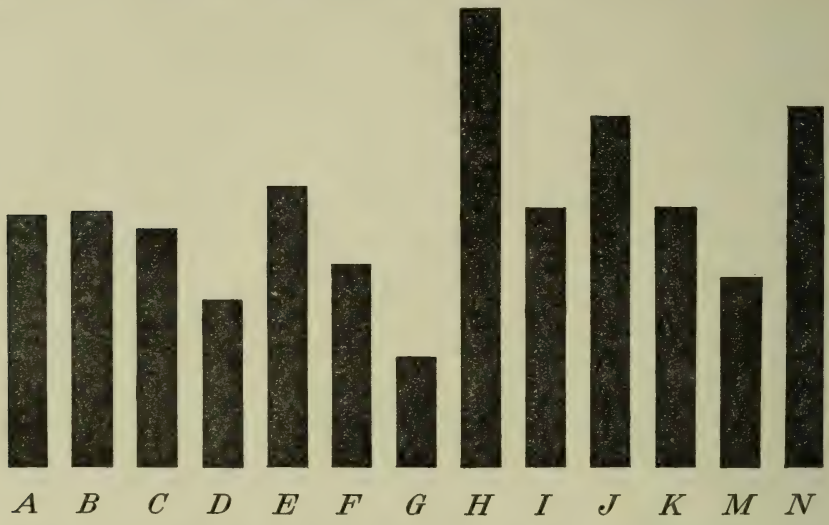

Fig. 21—Graphic Representation of Relative Cross-Breaking Strength of the Standard Roofing Tile Clays.

Purdy[1], in a very careful and extensive test on the measurement of linear air shrinkage of clays, says that this factor varied as much as 133 per cent. from the average, and that such data must be wholly unreliable. Although extreme care was exercised in preparing and handling the test, he says that the large variations in the results were a surprise to the operator.

The volume air shrinkage was found to vary within much more reasonable limits, although such variations as 33.8 per cent. were found. The reasons given for such errors are charged to the smallness of trial-pieces and the personal factor. In view of Purdy's results, both linear and cubic shrinkage were carefully measured on the standard roofing-tile clays as a possible check, one to the other.

Linear Air Shrinkage.—Taking up first the linear air shrinkage: The trial-pieces were made by taking the previously prepared and aged clay, and passing the same through a one-inch by one-inch die attached to a small plunger or piston machine. The clay was fed into the barrel of the machine in lumps or balls, packing the chamber as full as possible. The plunger was then moved forward by a screw movement, and as the clay issued from the die it was cut off into four and one-half inch lengths. Ten trial pieces of each clay were thus made. These bars were placed on metal pallets, lettered, numbered, and stamped

[1]Purdy, R. C. Illinois State Geol. Sur., Bull. IX, p. 133.

with a 100 mm. distance marker. To determine the water added for plasticity, the trials were weighed upon leaving the die. Then, at intervals, they were weighed and measured, giving the results in Table 10.

TABLE No. 10.

Table showing loss of Water, and Corresponding Air Shrinkage of the Standard Roofing Tile Clays, from Time of Making to Complete Dryness.

Designation of clay.	Per cent loss of water.	Per cent of drying shrinkage.
A	4.19	1.75
	7.69	4.50
	16.78	5.00
	19.23	5.50
	20.75	5.50
	20.62	5.50
B	3.18	1.50
	9.26	2.75
	15.01	3.00
	15.97	3.00
	16.22	3.00
C	5.71	2.00
	13.21	4.50
	21.42	4.50
	23.21	4.50
	24.28	4.50
D	13.88	3.50
	20.48	3.50
	21.52	3.50
	21.87	3.50
E	6.25	4.00
	15.97	6.00
	20.83	6.00
	21.52	6.00
F	6.94	4.00
	17.01	5.00
	21.52	5.25
	22.22	5.25
G	1.80	.50
	7.34	2.00
	13.85	2.00
	15.66	2.00
H	3.54	2.00
	5.67	3.50
	12.05	6.50
	19.85	7.00
	22.62	7.25
I	2.00	1.00
	6.66	3.25
	10.00	4.00
	13.66	4.00
	15.33	4.25
	16.33	4.25
	17.33	4.25
J	6.33	2.50
	8.80	3.50
	13.73	5 50
	20.07	6.00
	21.47	6.50
	23.94	6.50
K	6.25	3.00
	9 02	4.00
	12.50	5.00
	17.35	5.50
	19.79	6.00
	20.48	6.00
L	1.80	1.00
	3.31	2.00
	5.92	3.50
	6.18	4.00
	9.98	5.50
	11.43	6.00
	13.38	6.00
	19.12	6.00
	20.56	6.00
M	1.54	.50
	3.08	1.50
	5.27	3.00
	9.40	3.50
	11.53	3.50
	13.58	3.50
	17.14	3.50
N	1.95	1.00
	4.02	2.50
	5.21	4.00
	6.84	4.00
	10.28	4.50
	12.33	5.00
	13.90	5.00
	16.90	5.00
O	2.09	1.00
	3.82	2.00
	6.42	5.00
	7.30	4.50
	11.95	5.50
	12.48	5.50
	13.32	5.50
	17.52	5.50
	21.90	5.50

In order to make this mass of data easier to interpret, it has been plotted to scale on co-ordinate paper, and the points connected, making the curves shown in Figure 22. The irregularity of the periods for taking readings and the few readings obtained in the early part of the drying tests leave much to be desired, but, after all, the curves are of assistance in visualizing the data. From these tables and curves, it is possible to divide these fifteen clays into two tolerably distinct groups.

First. Those clays which continue to show a steady shrinkage as long as the expulsion of water continues. Samples J, H, K, I and E belong here. J is the type, continuing to shrink up to 21.5 water loss out of a total water expulsion of 24.

Second. Those clays which cease or nearly cease shrinking when 50 per cent. of the water has been expelled. Samples O, A, F, L, N, M, G, B, D and C belong here. O is the type, being almost through shrinking at 6 per cent. water loss, but continuing to lose water up to 22 per cent.

The second group may for convenience be divided again into subgroup A, those which show a high shrinkage—5 per cent. or above—as O, A, F, N and L, and subgroup B, those which show a low shrinkage—4 per cent. or below—as G, B, D, C and M.

The theory has been long held that the water required to make a clay plastic must be in excess of the interstitial or pore space of the clay, and that after this open space is filled then further addition of water widens the distance between grains of clay, causes them to float and move on each other more easily, and by its subsequent removal causes the shrinkage of the clay in drying. This theory is borne out by the curves shown in Group 2, both in the high and the low sub-groups. But in Group 1 we have clays whose behavior does not at all agree with this familiar conception of the mechanics of a plastic clay mass. These clays become less in volume almost up to the very last of their water supply, and if these data can be reproduced and extended in other clays, they would call for a remodeling of this old conception.

It is believed that this method of examining the drying properties of clays by plotting the shrinkage vs. loss of water in curve form promises to be of practical value.

For example, take clays of the type of G or D. It can be seen at a glance that these clays could be dried easily and safely up to the point of their maximum shrinkage. Their loss of water has a relation to the shrinkage of four to one or above, while clays like H and K, having a relation of the loss of water to shrinkage of about three to one would be more difficult to dry. In other words, their rate of drying would have to be decreased to about one-half of that required for G and D.

Again, clays H and K would have to be dried very carefully right up to complete dryness, while clays like G and D could have their rate of drying forced, from the time at which their shrinkage ceases, up till all water is expelled.

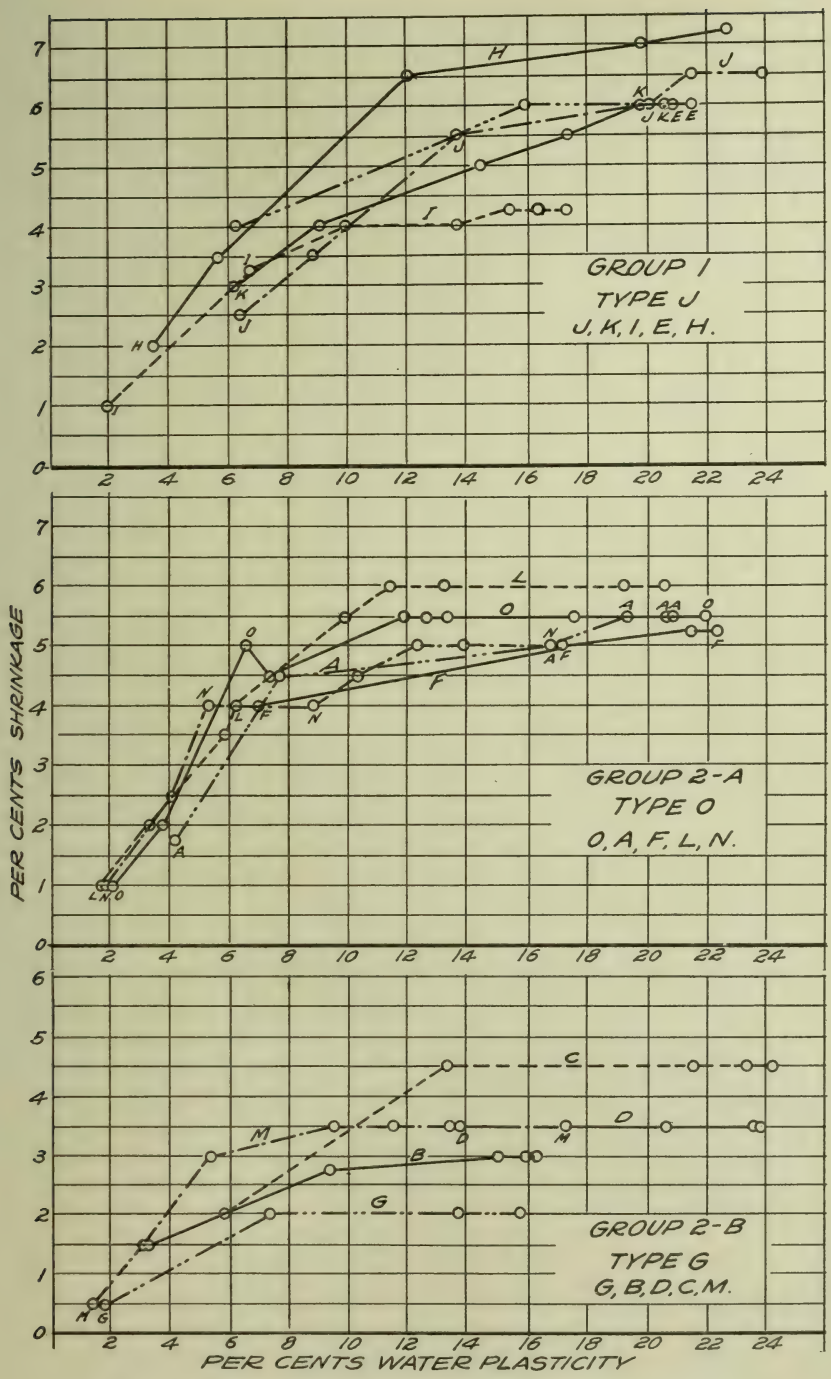

Fig. 22—Curves Showing Rate of Shrinkage in Drying.

Trial Pieces for Volume Shrinkage.—Owing to the die used for the linear shrinkage trials being improperly constructed, and requiring too much time to produce a perfect bar, it was discarded and a new outfit used for the volume trials. This consisted of a cast iron die box having a two-inch by two-inch opening extending through it. Closely fitting the opening was a piston which was used to compress the clay in the mold and then to expel the same. The clay was carefully made into a roll that would just enter the opening. The die standing vertically on a table, the roll of clay was dropped in, the piston was inserted and then pressed down until the clay completely filled the die. Turning the die box on its side, the rectangular mass of clay was forced out. This piece, approximately two inches by two inches by four inches, was now cut into cakes three-fourths inch by two inches by two inches by means of a wire cutter. Ten trials were thus made. Finally, each in turn was returned to the same die box and firmly repressed, to destroy the rough edges and surfaces from the wire cuts. Each trial was at once weighed, lettered and marked with a 50 mm. marker. Then all were placed in pans of water-free kerosene, where they were allowed to remain twenty-four hours. Each trial in turn was then measured for its volume in a Seger volumeter.

The volumeter consists of a glass jar with a capacity of about four litres, having a broad mouth and closed with a ground glass stopper. Through the center of this stopper is a circular opening, into which fits a glass tube, which has an expanded bulb at its upper end. Through this bulb and tube the interior of the jar is open to the air.

At the base of the jar in one side is a glass stop cock, which is connected to the burette shown to the right of the jar in the cut. The burette holds 125 cubic centimeters, and is graduated to tenths of a cubic centimeter. The upper end of the burette is expanded into a bulb, which acts as a reservoir for the liquid drawn up from the jar by means of suction applied to the top of the burette. The glass tube inserted in the stopper of the jar has a zero mark placed upon it, just below the bulb. At the same level on the burette is a second zero mark. Thus the apparatus is standardized by filling the jar until the liquid exactly reaches the zero marks.

To use the volumeter, oil must be used for the unburned trials, while water could be used for any substance that will not disintegrate when immersed in it. After the jar has been filled to the zero marks, the oil is sucked or drawn out of the jar up into the burette and its bulb. When a sufficient quantity has thus been removed from the jar, the stop cock in the burette is closed. The glass stopper is then removed from the jar, and the trial piece which has been previously saturated with oil is lowered into the jar, the stopper replaced, the burette stop cock opened, and the oil allowed to run back into the jar, care being taken to stop it exactly at the zero mark in the glass

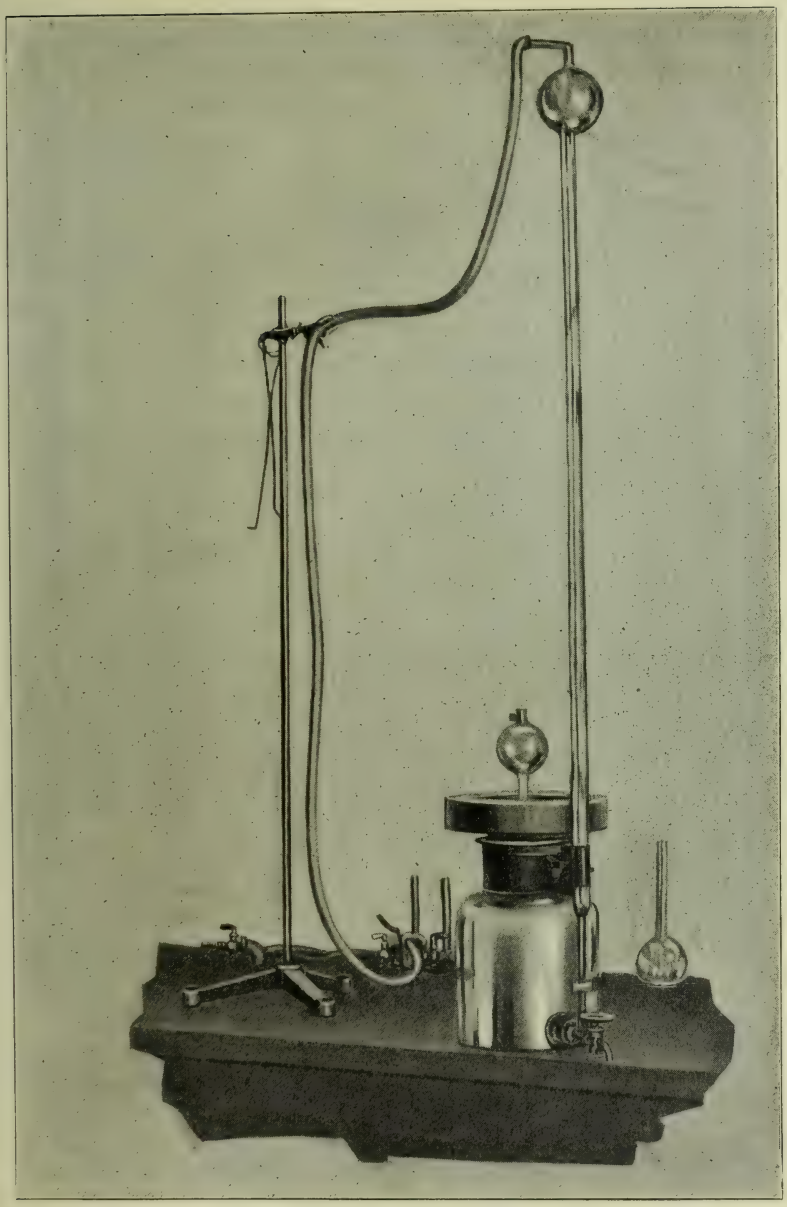

Fig. 23—Seger Volumeter.

stopper. There will remain in the burette, and measured by it, a volume of oil in cubic centimeters equal to the volume of the trial piece placed in the jar. After the volume has been read off, a portion of the oil is again drawn up the burette, the trial piece removed, and a second stan-

dardization of the liquid made. Thus the work is carried on. Much care must be given to the operating of a volumeter in order to get consistent data; many small factors creep in to vary results. For instance, after the oil has been drawn up into the bulb of the burette, a trial placed in the jar, and the oil allowed to flow back, it will be found that unless a considerable time is allowed for the oil to drain down the sides of the burette, that an error of considerable importance will be made—that is, the volume will be underread. Again, much care should be used in having the trial pieces free from excess oil upon entering the jar and in seeing that the oil is not spattered out or lost upon removing the lid.

For lowering the trials into the jar a little device was used consisting of a piece of flat sheet iron, so bent that the step formed had its center of gravity directly under its vertical part. In the top of the piece was a hole, through which the lifter and its charge could be raised or lowered into and out of the jar by means of a small hook. The lifter must of course be left in the jar while standardizing.

All of the trial pieces used in this test were prepared as before noted, and their volume carefully measured in the volumeter. After being removed from the volumeter, they were allowed to air-dry for several hours, and then placed in a drying oven and brought to dryness, after which they were carefully weighed, measured and allowed to soak in oil a second time, this time for a period of 48 hours. The volume of each trial piece was again taken, giving the following results based upon the average:

TABLE No. 11.

Comparing the Volume Shrinkage of the Standard Roofing Tile Clays with Their Measured and Calculated Linear Shrinkage and Water Content.

Sample	Average Initial Water Content in Per Cents.	Average Volume Shrinkage in Per Cents.	Average Measured Linear Shrinkage in Per Cents.	Calculated Linear Shrinkage in Per Cents.
A	16.01	13.47	3.94	4.71
B	14.23	7.34	3.32	2.51
C	20.16	12.63	4.90	4.40
D	18.80	8.60	3.90	2.95
E	16.80	12.43	3.94	4.33
F	19.08	12.96	4.03	4.52
G	11.37	3.09	1.66	1.04
H	19.83	19.36	6.00	6.92
I	14.69	8.49	3.96	2.92
J	17.72	17.02	5.98	6.03
K	17.47	13.93	4.88	4.88
L	16.67	16.96	4.88	6.01
M	15.58	8.25	3.92	2.83
N	16.13	9.38	3.46	3.23
O	18.74	12.08	3.82	4.20

The above figures of volume and linear shrinkage, with the per cent. of initial water, are taken from the average of ten samples in each case. The linear shrinkages given in column 5 were calculated from the observed volume shrinkage by the Purdy formula.[1]

While the measured and calculated shrinkage do not check each other closely, there is a very general similarity in them.

Much care was taken in obtaining the two kinds of measurements. The linear shrinkage marks were cut into the trial pieces by sharp-pointed dividers, set to read 50 mm. When the trial pieces were dry, they were measured by a Vernier shrinkage scale, which read to the second decimal place. The differences in the measured and calculated shrinkages no doubt come from the inability of clay bodies to shrink perfectly. Structural flaws form inside clay wares, owing to the inability of the highly viscous mass to completely obey the laws of a fluid. No piece of plastic clay ware can be broken open and found free from structural defects. Hence, no formula based on a perfect volume change can be expected to agree other than superficially, where it is known that the volume change is highly imperfect.

It will be noted that clays H and J have the highest volume and linear shrinkages of the entire list, while clay G has the lowest. These same clays have the highest and lowest per cents. of initial water. By referring to Table No. 8, it will also be seen that clay H has the greatest cross-breaking strength, and clay G the lowest. Thus we can see that in this case there is a close relation between the percentage of water required for plasticity and the shrinkage and strength of the clay.

BEHAVIOR IN BURNING.

The properties which weigh in making one clay more desirable to work than another in the burning process are:

1st. Freedom from a tendency to snap or pop in heating up.
2nd. Ease of oxidation.
3rd. Wide vitrification range.

Nearly any clay can be burnt successfully if sufficient time and skill and expense can be brought to bear on it, but the ease with which some clays can be burnt and the difficulties which arise with others make these properties of very real importance in estimating the value of any given sample.

The properties which are developed in the clay by the burning process—the color, strength, hardness, frost resistance, volume change etc.—are really separate from the actual behavior in burning and will be considered under a later heading.

[1] "If a unit cube shrinks so that each edge is decreased by linear length 'a,' then the new length of the edges becomes (1—a). If the decrease in volume of this same cube be represented by 'x,' then the new volume will be (1—x). Since the edges of the cube are now (1—a), its volume can also be represented by $(1-a)^3$ hence $(1-a)^3$ is equal to (1—x), or $a=\sqrt[3]{1-x}$." (Bull. IX, Illinois Geological Survey p. 133.)

Snapping.—This peculiarity is not a very common defect of clay wares, but is a serious drawback to a clay when it does occur. The clay on heating shatters or flies to pieces explosively, in whole or in part, and not only ruins the piece affected, but often does much harm to the surrounding pieces—especially if they be glazed and subject to easy disfigurement.

The idea is common that snapping or popping is due wholly to the too rapid expulsion of moisture, so that steam is generated faster than can escape from the pores of the clay, and, as a consequence, flakes or chips of the ware are blown off to vent the interior pressure. Beyond doubt such steam explosions do occur, and commonly too. Especially in piston-made wares, like sewer-pipe, in which longitudinal laminations are extensively produced in the die, the steam seems to collect in these cavities and blows off large flakes, and the resultant product is usually worthless or nearly so. Any clay will fail from this cause, if its treatment is conspicuously over-hastened, and time is not afforded for the water to peacefully vaporize, but in general those clays which give the most trouble are the fat, rich, plastic clays of tight body. Such clays manifest a stronger tendency to laminate, or to form layers separated by cracks or unbonded zones, and thus help to produce this defect, both by hindering the easy escape of steam and affording accumulation zones for it to gather in until the danger point is reached. Weak, porous, sandy clays are not given either to holding back the steam or forming laminations, and hence in such clays steam-popping is at a minimum.

But this form of popping is the easiest to regulate, because its causes are understood. Real snapping is not due to this cause. It develops in thoroughly dried clay wares and hence cannot be a water or steam trouble. Clays affected by it fly to pieces or chip off from the surface and give great trouble. In general it is close-bodied, dense clays which snap. The cause has never been adequately studied, but is probably due to unequal expansion or too rapid heating. In the fifteen samples tested for this report, no snapping occurred in any of the trial pieces produced, showing that these clays are not affected. In another clay, subsequently tested in the same manner, snapping did develop. The likelihood of developing trouble from snapping is greater, of course, in laboratory experiments in small kilns than in large kilns in commercial work, on account of the tendency to quick heating in small kilns.

Oxidation Behavior.—Clays contain a number of mineral and organic constituents, besides the silicate of alumina which constitutes the plastic cementing material which gives character to the mass, and in burning a large number of different chemical reactions may be occurring. In general, these reactions are of two sorts—destructive and con-

structive. The former tend to break down the original constituents, drive out all of the volatile elements, and bring what is left into a condition of quiet equilibrium—i. e., a state where further chemical changes are not taking place. Only the less volatile substances usually remain when the clay has reached this stage, such as silica, alumina, iron, lime, magnesia, and the alkalies, and these substances are present partly as free oxides, and more largely as silicate compounds, more or less broken down from the mineral forms in which they originally existed.

The second or constructive changes are those occurring in vitrification and fusion, by which the oxides and minerals left in the clay mass are brought into new union by additional heat, and with this new partial combination comes a new set of physical properties, differences in color, strength, hardness, density, elasticity, etc.

The first group, or destructive changes, are therefore, seen to be preliminary or preparatory for the final hardening or vitrification of the clay, and no clay can be satisfactorily vitrified until its minerals have been brought to a proper condition by this preparatory treatment. The preparatory process itself is divided into two stages called dehydration and oxidation. The former concerns itself with the expulsion of the combined water from the kaolinite and other hydrous minerals of the clay. The latter concerns itself with the burning out of the organic bodies, such as wood, leaves, grass, roots, peat, lignitic matter, coal graphite, bitumen, or oily matter, and with inorganic combustibles like sulphur from sulphides of iron and similar minerals, and also with the conversion of all oxides that are left in the clay mass into the state of equilibrium before mentioned, by giving up a part of their oxygen, or taking on more of it.

The dehydration and oxidation reactions are not differentiated from each other clearly in the time of their occurrence, but oxidation changes usually last the longest, and require a higher temperature to complete them, though some parts of the oxidation may begin as early or earlier than any of the dehydration changes.

Clays show a wide difference in behavior in the ease and completeness with which they undergo this preparatory treatment. Some clays contain almost no oxidizable matter, and are ready to go ahead for vitrification as soon as the water is well out of them. Such clays are very "easy" to handle. Others are so full of carbon, iron and sulphur compounds that they are actually combustible like low-grade fuels. Such require the most extreme care, and often specially designed kilns, to make it possible to produce marketable wares from them.

In general, clays show by change of color when they are through the oxidation period. The presence of carbon or sulphur is indicated in a partially burnt clay by a black or dark discoloration. When this disappears from the center of the ware, then it is known that these substances no longer remain in quantities sufficient to do further harm. At

the same time, the iron which up to this time may have been existing in unstable forms of blue, green, gray or yellow colors, now takes on the usual brick-red tint in common clays. In fire clays, where the iron is much less in quantity, the characteristic buff tint is produced. The loss of the center discolorations and the assumption of the oxidized iron color is evidence that the clay is prepared for vitrification.[1]

While the roofing tile manufacturer is usually little troubled by oxidation difficulties in his clay, owing to the extreme thinness of the ware and the consequent ease with which oxygen permeates the mass and does its work, and also the openness of the setting, by which the air secures easy contact with the wares, still it was thought advisable to conduct a careful experiment to show the extent to which the standard series of roofing tile clays do really offer oxidation difficulties, and thus obtain a basis for judging how far oxidation troubles should be allowed to weigh against a clay under consideration for this particular industry.

The cross section of ordinary roofing tiles being so thin, it was thought better to mould up the clays into test pieces of much thicker cross section, in order to require a longer treatment for oxidation and thus form a better opportunity to draw comparisons. All of the standard clays were passed through a 20-mesh screen, tempered and aged, as described earlier, and seven brickettes of each, two inches by two inches by four inches, were then made in the die box before described. At the center of each trial, on all four sides, a light indentation was made to assist in breaking the brickettes at the desired point after drawing from the kiln. The trials were all carefully dried, and were then set in a small down-draft test kiln, in such a manner that a complete set of all of the standard clays could be taken out at a single drawing. The firing was done by coke, with a large excess of air passing through the kiln. To better control the temperature, a pyrometer was used. Time and temperature observations were carefully made at intervals, and the curve shown in Figure 24 was drawn to indicate the progress of the heat treatment. As each draw was made, the trials were placed on the floor, and with chisel and hammer they were carefully broken apart along the indentation lines.

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[1]See in this connection:

Orton. The Role played by Iron in the Burning of Clays, Transactions American Ceramic Society, Vol. V, page 377.

Orton & Griffin. The Influence of Carbon in the Burning of Clay Wares. Bull; 2, National Brick Manufacturers' Association, Indianapolis, 1905.

Orton & Staley. The Status of Carbon Iron and Sulphur in Clays during the Various Stages of Burning; Bull. 3, National Brick Manufacturers' Association, Indianapolis, 1908.

Jackson & Hopwood. Trans. North Staffordshire Ceramic Soc. The Coloration of Clay Wares, 1902, p. 93.

Hopwood, A. Trans. English Ceramic Soc. The Changes in Color of Clays on Ignition in Clay Ware Kilns, 1903, p. 37.

In Figure No. 25, page 616, it will be observed that an attempt has been made to represent graphically the results of the experiment on the rate of oxidation of the standard roofing tile clays. The various trial pieces were numbered in the order in which they were drawn from the kiln. Corresponding numbers are placed at the foot of each column in Figure No. 25, as well as the duration of the burn in hours at the time of the draw. An effort has been made by shading to represent the intensity of the color of the unoxidized cores in the various trial pieces. For instance, clays F, I, A, B are shown with areas lightly shaded, while clays J, N, E, H are shown black, the shading approaching the depth of color intended in each case.

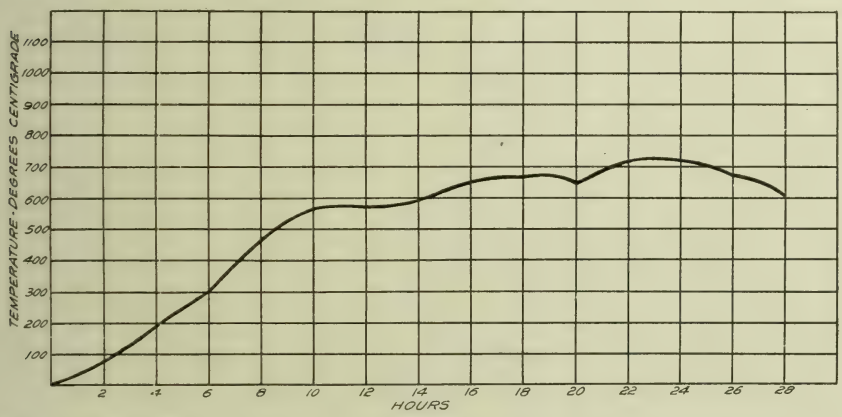


Fig. 24—Time-Temperature Curve, Showing Heat Treatment of Test Pieces.

Draw No. 1. Taken at 10 hours after the beginning of the burn. Temperature 565° centigrade. It will be observed in Figure No. 25 that out of the fifteen clays tested, only one, clay D, was completely oxidized at this draw, while clays F, I, A and B had been oxidized to a depth of about one-half inch on all sides, the unoxidized area being of a faint gray or blue-black color. At the same draw, clays K, M, O, L, G, C, J, and N had oxidized to a depth equal to or greater than F, I, A, and B, but the color of the unoxidized area was much darker, indicating a much larger amount of material to be oxidized. Clays E and H had only oxidized to a very shallow depth, less than one-fourth inch on all sides. In both of these cases, the central area was of a solid coal-black color.

Draw No. 2. Taken at 12 hours. Temperature 570° C.

Upon breaking open the trials from this draw, it was found that clays F and I had become completely oxidized, while clays A, B, K, M, O and G had an area of three-fourths inch to one inch in diameter still remaining unoxidized. Clays L, C, J and N contained areas of one inch to one and one-half inch in diameter still unoxidized, and in

clays E and H, the oxidation had proceeded but about one-eighth inch further in than it was in Draw No. 1.

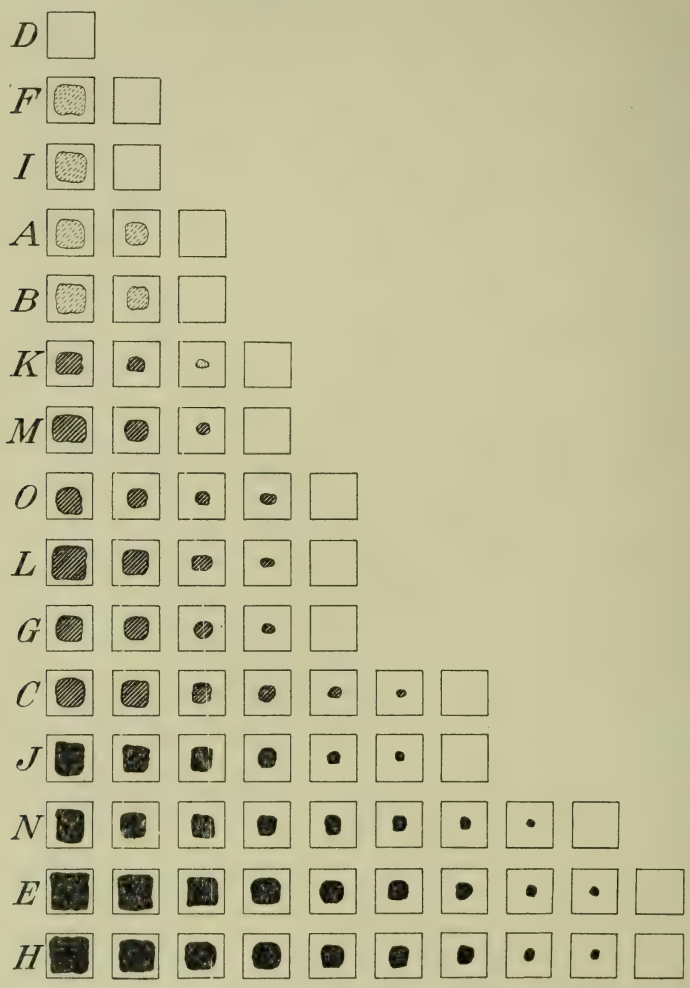


Fig. 25—Sketch Showing Progressive Oxidation of the Standard Roofing Tile Clays at Various Stages of the Burning Process.

Draw No. 3. Taken at 14¼ hours. Temperature 587° C.

Two more clays, A and B, had reached complete oxidation. Clays K, M and O only retained a small area unoxidized, about equal to the cross section of a lead pencil. In clays L, G, C, J and N, the oxidation had proceeded slightly less than in trials K, M and O, although all showed a marked change from draw No. 2. Clays J and N made the least gain. In clays E and H, the unoxidized portions had been reduced very little, but uniformly.

Draw No. 4. Taken at 15¼ hours. Temperature 620° C.

Two more clays, K and M, were found to have reached complete oxidation by the time of making this draw, while clays O, L, G and C retained but a very small area unoxidized. In clays J and N, the dark areas, while still darker than O, L, G and C, had undergone a marked decrease in size. The changes in clays E and H were noticeable, but small.

Draw No. 5. Taken at 20½ hours. Temperature 660° C.

Under the influence of the slightly increased temperature and the increased duration of time, clays O, L and G had reached complete oxidation, while N still contained a small area of black core. Clays E and H had lost their usual proportion of black area, but still contained a very dark core about three-fourths inch in diameter.

Draw No. 6. Taken at 24¾ hours. Temperature 730° C.

At this draw, trial-pieces C, J and N still retained a small area of core, not much reduced from that of No. 5. In trial pieces E and H, the core had only been reduced a very little, indicating that the oxidation in these clays was progressing very slowly, notwithstanding an increase of temperature and a time period of about 4 hours.

Draw No. 7. Taken at 28 hours. Temperature 605° C.

Observations at this draw showed trial pieces C and J to be complete in their oxidation, while the three clays N, E and H were still showing unoxidized areas about the size of a five-cent piece. Unfortunately the work could not be carried further, owing to the fact that only seven sets of trial pieces had been placed in the kiln. It had been thought that all of the clays would be completely oxidized at the end of a 24-hour period, and that seven draws would prove sufficient, but such was not the case. In order to complete the chart, the three clays N, E and H have been plotted as they would have appeared if the same rate of decrease of core had been maintained from there on to the finish as had been shown in the seven first draws. Using this same rate, and 4-hour intervals, clay N would have been completely oxidized at the end of 36 hours, while clays E and H would have taken 40 hours, provided the temperature had been held about constant.

Significance of this data.—Of the fifteen clays studied, only one clay, D, was found to be entirely free from unoxidized material at the end of 10 hours.

This clay in its natural condition is a deep-red or chocolate-colored shale, the color indicating that the iron present in the clay had been deposited in the ferric form, and that no carbon or reducing materials were deposited with it, to serve as a means of reducing it later.

In so far as oxidation is concerned, clay D, if made into roofing tiles, could be set tightly in the kiln, and fired fast, with no danger. It is the only clay of the series of which this could be said.

Clay A was oxidized in 12 hours. It is quite possible that the actual amount of material to be oxidized in this clay is as great as in

N, E and H, but the nature of the material is different. It is a shale whose structure is broken up by a high content of sandy material, making the body so porous that oxygen can readily permeate the tiles, and the carbonic acid generated can escape. N and H, on the other hand, are fine-grained alluvial deposits, and E a close-grained glacial clay. The fineness of grain in the three latter clays prevents the free permeation of the body by the oxygen, hence the oxidation period of the burn must be extended to properly provide for this.

Notwithstanding the fact that clay A was seemingly oxidized easily, it is known from actual use of this clay in the manufacture of shingle tiles that it gives trouble in the matter of center marks and black core, unless the burn progresses very slowly. Ten to twelve days are used in the proper burning of the tiles. The mode of setting the shingle tiles made from this clay is very dense and close and anything but conducive to easy oxidation or successful, rapid burning.

While it might appear, from the oxidation trials shown in this work, that much trouble might be expected in the burning of roofing tiles from such clays, such is not really the case. The fact that roofing tiles are thin wares, and that the shape of all tiles, excepting flat shingles, is such that tight setting is impossible, largely assists in the rapid oxidation of the tiles. The temperature at which this test was executed was also lower than necessary for safe oxidation, and the results were slower than in commercial practice on this account. However, oxidation at temperatures above 800° to 850° Centigrade has been shown by Orton[1] to be a common cause of different colored center-marks, even though all carbon and sulphur are finally expelled from the ware. In actual kiln firing, the oxidation begins at 350° or 400° and progresses till about 900°, at which point it seldom continues to make much headway. But in large kilns passing from 400° to 900° it usually stands for considerable time-periods, 24 to 48 hours or more, and this test shows that even in wares two inches square, not more than 40 hours would be required.

It was not the purpose in making this test to try to establish a definite time for the oxidation period of any clay. In a search of ceramic literature for data, nothing could be found that would enable one to make safe conclusions upon the relative speed of oxidation in trial pieces and full-sized wares, and no attempt has been made to do so in this discussion. It is clear, however, from the work done, that clays like E and H will take very much more time than A or B, and that roofing tiles, while easy to oxidize as a class, are nevertheless not at all exempt from troubles in this connection.

An interesting point has been brought out in this work, in the study of the three clays, I, K and J taken singly, and the mixture L, formed by their blend. It will be observed that I shows very little

[1]See references cited on page 614.

trouble in oxidizing, K a little more, and J very much more: in fact, the latter clay would be considered bad. The mixture of these three clays in the proportions used by the company furnishing them is an improvement over J, but is worse than K alone, and very much worse than I, which by itself would be considered as a good or easy clay to oxidize. This company is thus taking a very easily oxidizable clay and by adding others to it is greatly increasing the danger of getting black-cored and center-marked ware. So far as oxidation alone is considered, it would be better to discard J entirely, and K if possible.

VITRIFICATION RANGE.

General Discussion.—As explained under oxidation behavior, the changes occurring in the second part of the burn are constructive in nature, as a body is produced having physical properties entirely different from those of the original material as a whole or of its component minerals. The burned clay is a partially fused silicate mass—the extent to which the fusion has gone depending on the length and temperature of the firing, the mineral mixture present, the fineness of grain of these minerals, the completeness of their oxidation treatment, and many other factors.

All clays, in producing marketable goods, must pass through some of this constructive heat work—how much, depends on the kind of product sought. But while practically all clays must undergo such a change, the rate at which the change takes place varies very greatly and constitutes one of the important criteria in deciding on the suitability of clays for use. The difference between clays in this respect ranges from those which harden, shrink, and reach their best structure interval of 50° centigrade in a few hours' time, to others which require 300° or even 400° centigrade and several days' time to bring about the desired degree of combination. Without going, at this place, into any discussion of the causes of these wide differences, it is desired to know what the fusion habit of each of the standard series of roofing-tile clays is, with a view to interpreting the suitability of other clays for this purpose.

A wide or gradual vitrification range has usually been considered as of more importance for roofing tiles than for most clay products, because quick or sudden vitrification is usually associated with rapid and excessive changes in volume, with warpage and deformation, with rolling or falling over in the kiln, etc., and these difficulties are all extra severe on wares of large area and thin cross section, like roofing tile.

The determination of the vitrification range of a clay can most conveniently be done by firing a series of test pieces of suitable shape and size through a series of increasing temperatures, withdrawing one or more at each successive temperature stage, and measuring their various resultant physical properties. By the progressive change in these properties, especially in the color, hardness, porosity, specific

gravity, and shrinkage, the progress of the fusion reactions may be approximated.

It will at once be appreciated that a thorough study of the vitrification range involves or constitutes a thorough study of the final physical properties which the clay takes on by burning. These various properties, such as hardness, porosity, specific gravity, strength, color etc., are inherent properties of the clay, or latent within it, and they furnish a large share of the evidence in deciding the fitness of the clay for any purpose. So that we wish to know, not only the *rate* at which these properties develop in burning and the temperature range needed to draw them out, but we also need to know what the final status of the burnt clay is in each of these various respects. For instance, a clay may be shown to have a wide and perfectly satisfactory vitrification range, but its hardness, strength, color, etc., may be wholly unsatisfactory from the standpoint of producing a commercial product notwithstanding.

Therefore, in the following studies made on the test pieces drawn progressively from the kiln as the temperature rose, the two points of view will be preserved and considered separately.

The trial pieces chosen for burning for this test were the same as had been used in determining the drying shrinkage, viz., bars one inch by one inch by four and one-half inches, made on a small hand-power plunger machine. There were ten trial pieces of each clay, carefully marked with the sample letter, and numbered 1 to 10, inclusive. Each bar was also stamped with marks one hundred millimeters apart on the plastic clay; these marks came closer together as the clay shrank. In setting these trial pieces for burning, the pieces marked No. 1 of each clay were placed together, the No. 2's and each following number being similarly assembled. Each lot was placed in a convenient position for drawing. The firing was done in a Caulkin's Revelation kiln, fired by natural gas. With each lot of trial pieces was placed a standard pyrometric cone at the fall of which it was desired to draw the lot, as follows:

No. 1	Cone 010	No. 6	Cone 1
No. 2	Cone 08	No. 7	Cone 2
No. 3	Cone 06	No. 8	Cone 3
No. 4	Cone 04	No. 9	Cone 4
No. 5	Cone 02	No. 10	Cone 5

Thus, when cone 010 melted, all of the trial pieces No. 1 were drawn; at cone 08 all of the trial pieces No. 2, and so on. To prevent the trial pieces from cracking by cooling suddenly in the air, and to better develop the color, a small up-draft kiln standing near the Caulkin's kiln was fired up to a good red heat and kept in that condition. The trial pieces as drawn from the test-kiln at the specified cone-temperatures were quickly transferred to the up-draft kiln. When the entire ten lots had been

transferred, the kiln was allowed to cool gradually down to the atmospheric temperature. This precaution is highly necessary, if a normal color or strength is to be obtained.

On these ten lots of trial pieces, the following properties were studied and measured:

1—Color.
2—Hardness.
3—Porosity.
4—Specific gravity.
5—Shrinkage.
6—Warpage and deformation.

Color.—A good, clean attractive color is a *sine qua non* with a successful roofing tile. If the material does not burn to a good, clean color in itself, the use of a slip of clay or engobe, or some body-colorant, must be used.

In this country at the present time, only one natural color is really available for roofing tiles, and that is red. From time to time in the past years, a few tiles have been made up from buff burning-clays, but the demand for them has been very meager, and their manufacture soon abandoned.

Of twelve plants inspected in 1908, eight were producing tiles of good red color from natural clays or shales, without the use of slips, engobes, or admixed mineral colors. The ninth and tenth plants were using a red-burning slip-clay to mask the poor color obtained from the raw material in use.

The eleventh plant was using a slip clay, but with a very different object in view. Their raw material in itself burns to a very nice red color, but, according to the statement of those in charge, it is rough and pimply. The slip is used to improve the surface finish of the tiles, so that they will remain bright and clean after being put in position on the roof. The above claim is probably well founded, in their particular case at least, for the following reasons:

The tiles at this plant are pressed on plaster dies. In the nature of the case it is impossible to keep the surface of a plaster die in perfect condition. It soon becomes badly pitted with minute pores or open cells, so that the tiles made upon it receive the reverse impression of the pitted die surface, producing very rough, pimpled surfaces.

If such tiles are soft or medium burned, they will, when placed upon the roof, very easily catch dust and dirt, becoming black and begrimed within a very short time. Had these same tiles been coated with a good slip, their roughness would have been largely obliterated by the slip filling up the minute cavities on the surface of the tiles.

In the burning at the above plant it is the practice to stop at a point considerably below complete vitrification, or in other words to leave the tiles still quite porous. Hence, upon placing them upon the roof, it would be natural to expect them to take up much dirt and become badly discolored. Thus, it is possible, by using a slip clay which vit-

rifies at an early period, to coat the tile-body with a vitrified covering, which will act much like a glaze. The product, instead of becoming weather beaten and dirty, will remain bright and clean by being washed with each rain.

If the above clay would stand a higher degree of vitrification than is at present given it, then the slipping of the tile would no longer be justifiable, owing to the extra cost and the loss by breakage during the operation. Should it be found that the clay, upon a higher vitrification, deformed very badly, then the present procedure of low-temperature burning, with the use of a good perfect-fitting slip clay, would be justified as the best method of handling a troublesome clay.

At the twelfth plant, a very different method is pursued to improve or change the color of the tile for special orders. A few per cent. of mineral-red (oxide of iron) is added to the clay as it is being pugged, thus mixing the colorant through and through the clay.

While the addition of the oxide darkens the natural color of the clay very materially, it was hard to see where it had improved the natural red color. It gave a dull or faded appearance to the tile thus treated. It has been repeatedly demonstrated, practically and experimentally, that it is impossible to obtain good, red colors by doctoring the clay with a free oxide of iron. This instance merely adds one more to the list of failures.

In taking up the study of the colors produced in this research it must be borne in mind that it is impossible to make any clay give its best color, when fired in small test-kilns, and cooled rapidly. From a previous knowledge of the colors obtained commercially from each of the standard clays tested, it was observed that the colors obtained with test-kiln burns check those obtained in the regular way very closely, with the exception that the colors are not so bright or clear.

While the terms used to characterize the various shades used in describing these results have a wide latitude, it has been the endeavor to use them consistently in the series. These data have been arranged in Table 12, pages 623 to 627 inclusive. It has also been thought worth while to include a column giving the percentage porosity of each trial piece in order to better associate the colors developed with the progress of the vitrification reaction.

Additional Color Trial.—A further study on the color of the various clays has been taken from the warpage trial pieces. These trial pieces were burned in a coke-fired kiln, under conditions which would more nearly approach the commercial than those of the vitrification test burn, in which the firing was by gas and the trial pieces were drawn from the kiln at the cone indicated. Although immediately transferred to a hot kiln for gradual cooling, still such conditions are not conducive to the production of the best colors which a clay is able to produce. The

TABLE No. 12.

Color Studies on Standard Roofing Tile Clays.

CLAY A

Drawn at Cone.	Colors Found on Cooling.	Percentage Porosity.
010	Light yellow-red	29.53
08	Slightly darker	25.77
06	Slightly darker than at cone 08	18.11
04	Deep red—A commercial color	11.52
02	Much darker red—A commercial color	7.48
1	Very dark red—A commercial color	4.95
2	Very dark red, bordering on brown	3.00
3	Chocolate brown	2.51
4	Chocolate brown (dark)	1.08
5	Blue black	1.25
	This clay gives its best color range from cone 04 to 02.	

CLAY B.

010	Very light yellowish red	31.07
08	Slightly darker red	31.12
06	Light red—A commercial color	26.80
04	Better red than 06—A commercial color	25.76
02	Same as 04—A commercial color	26.15
1	About two shades darker red—A commercial color	21.95
2	Dark red brown	19.29
3	Chocolate brown	12.57
4	Dark chocolate brown	14.04
5	Blue black	3.12
	This clay gives its best color range from cones 04 to 1.	

CLAY C.

010	Salmon-yellow	35.94
08	Slightly darker	35.02
06	Same	32.45
04	Much darker, through still a light red	17.00
02	Very good red—A commercial color	14.30
1	Dark red—A commercial color	7.41
2	Very dark red—A commercial color	5.22
3	Chocolate brown (light)—A commercial color	4.07
4	Chocolate brown (dark)	1.10
5	Bluish brown	....
	This clay gives its best color range from cone 02 to 1.	

TABLE No. 12—Continued.

Color Studies on Standard Roofing Tile Clays.

CLAY D.

Drawn at Cone.	Colors Found on Cooling.	Percentage Porosity.
010	Light red	32.85
08	Same	32.03
06	Yellowish red	33.29
04	Much darker red—A commercial color	24.59
02	Cherry red—A commercial color	13.04
1	Dark brownish red—A commercial color	12.62
2	Darker brownish red—A commercial color	10.12
3	Very dark brown-red—A commercial color	2.62
4	Bluish brown	0.74
5	Green	0.80
	This clay gives its best color range from cones 04 to 02.	

CLAY E.

010	Light pinkish red	38.42
08	Very light salmon	39.87
06	Same	39.34
04	Same	41.67
02	Same	40.10
1	Buff specks in a matrix of reddish buff	12.50
2	Same	26.24
3	Buff specks in a matrix of brown	1.90
4	Bluish or gray	2.72
5	Same	1.60
	There were no commercial colors developed. This clay would have to be slipped.	

CLAY F.

010	Light pinkish red	33.99
08	Somewhat darker, though still too light	31.83
06	Same	33.48
04	Light red, rather yellowish	23.65
02	Same	24.61
1	Dark brown	12.08
2	Dark brown	16.83
3	Very dark brown	2.93
4	Bluish	0.60
5	Same	1.24
	The nearest approach to commercial colors are obtained at cones 04 to 02. These colors are not good when compared to the standard tiles on the market. This clay should be slipped.	

TABLE No. 12—Continued.

Color Studies on Standard Roofing Tile Clays.

CLAY G.

Drawn at Cone.	Colors Found on Cooling.	Percentage Porosity.
010	Very light red, almost buff	28.31
08	Same	27.73
06	Much darker red	19.03
04	A shade darker, much better—A commercial color	16.19
02	Same—A commercial color	16.69
1	Dark red—A commercial color	8.22
2	Dark red-brown	9.10
3	Same	8.77
4	Same	8.42
5	Dark brown	7.82
	This clay gave its best color range at cones 04-02.	

CLAY H.

010	Light brick red	30.76
08	Same	24.88
06	Same	29.94
04	Much darker red—A commercial color	24.95
02	Same—A commercial color	25.37
1	Chocolate-red (light)—A commercial color	8.05
2	Chocolate-red (dark)—A commercial color	16.20
3	Very dark chocolate	1.65
4	Blue	2.56
5	Same	1.97
	This clay gave its best color range at cone 04-02.	

CLAY I.

010	Light yellowish red	33.04
08	Same, though a little deeper	33.33
06	Poor red with yellow specks	32.10
04	Same	32.17
02	Same	32.10
1	Darker, poor color, yellow specks	29.62
2	Chocolate matrix, yellow specks	23.88
3	Same	17.94
4	Same	15.32
5	Nearly black matrix, yellow specks	0.52
	At no point does this clay show a good color. It is best at cone 08.	

TABLE No. 12—Continued.

Color Studies on Standard Roofing Tile Clays.

CLAY J.

Drawn at Cone.	Colors Found on Cooling	Percentage Porosity.
010	Very light pink tinted buff	24.55
08	Same	22.98
06	Light yellowish brown or tan	11.22
04	Same	9.30
02	Same	9.15
1	Same	7.41
2	Olive green brown or tan	7.17
3	Same	7.40
4	Same	7.88
5	Light tan color	9.21
	There were no good colors developed by this clay. It would require slipping.	

CLAY K.

010	Yellowish red. Not commercial	17.53
08	Darker yellowish red. Not commercial	14.48
06	Much darker red. Commercial	8.24
04	Deep red. Commercial	5.77
02	Deep red. Some flash. Commercial	1.71
1	Same	0.65
2	Same	0.80
3	Overfired	....
4	Overfired	....
5	Overfired	....

CLAY L.

010	Light brick red	27.26
08	A shade darker, but still a poor red	24.82
06	Improved but still yellowish red—A commercial color	22.59
04	Darker red, but dull or dead—A commercial color	18.35
02	Same—A commercial color	15.50
1	A very little darker—A commercial color	15.63
2	Chocolate-brown, poor color	12.76
3	Same, but darker	10.55
4	Melted	5.20
5	Melted	4.45
	While there are a number of colors in this set which are reported as commercial, they are not very good, having too much of a yellow tint. Clay L is the mixture of clays I, J and K, as used in actual tile manufacture.	

TABLE No. 12—Concluded.

Color Studies on Standard Roofing Tile Clays.

CLAY M.

Drawn at Cone.	Colors Found on Cooling	Percentage Porosity.
010	Very light brick red	29.88
08	Light brick red	29.42
06	Much deeper red—A commercial color	28.49
04	Same—A commercial color	28.73
02	A shade darker—A commercial color	27.74
1	Much deeper red, rather dull—A commercial color	21.73
2	Chocolate-brown	10.73
3	Same	3.66
4	A very little darker	3.10
5	Same, but dead color	0.51
	This clay gives its best color at cones 06-02.	

CLAY N.

010	Very light red	37.12
08	Same	38.25
06	Gray buff	37.64
04	Same	37.20
02	Same	36.42
1	Darker gray	18.25
2	Same	17.86
3	Dark gray	5.68
4	Same	21.04
5	Yellow-brown (trial melted)	1.01
	There were no commercial colors in this set of trials. A slip clay would have to be used.	

CLAY O.

010	Light salmon yellow	27.31
08	Same	32.23
06	Slightly darker	29.04
04	A little darker red	22.85
02	Medium red color. A commercial grade	20.04
1	Drak red color. A commercial grade	8.84
2	Same. A commercial grade	11.74
3	Chocolate-red. Almost too dark	7.31
4	Same	3.92
5	Blue	5.35

trial pieces about to be studied were burned and cooled in the same kiln, hence giving better conditions for a normal color.

Clays A and B give their best commercial colors between cones 07 and 04.

Clays C gave its best colors at a little higher temperature, namely, cones 04 to 01. This clay scummed badly.

Clay D produced its best color at cones 04 to 01, though a fair light red is obtained at cones 09 to 07.

Clay E produced nothing but buff-colored trials, due to the lime present in the clay. These trials also show considerable popping from limestone.

Clay F gave its best red at cone 07, though the color is poor. All trial pieces of this clay were covered with scum or whitewash.

Clay G has a range of good color extending from cones 07 to 01, with 04 as the best point.

Clay H produces its best color from cones 07 to 04, with 07 as the best color. This clay developed numerous limestone pops, which would be strongly against it commercially.

Clay I is fairly good in color from cone 07 to 01, with trial pieces at cone 07 as the best.

Clay J did not produce any good colors, and furthermore the trial pieces were all coated with a scum.

Clay K in this burn has given commercial colors from cones 09 to 04, with the 07 and 04 trial pieces the best.

Clay M gives good commercial colors at cones 07 to 01, but is badly discolored with scum.

Clay N is pink at cone 09, but all the balance of the trial pieces are buff, due to its large lime content. These trial pieces are, in addition to their poor color, scummed and lime-popped.

Summing up the results of the entire series, clays A, B, C, D, G and M have given the best results. Clays H, K and I have given fairly good results, the colors being too light a red, or yellowish. Clays E, F and N would have to be given a coat of slip clay in order to make them commercial.

A closer grading of the colors obtained in this work would give first place to clays A, B and D.

From the foregoing, Table No. 13 has been abstracted.

TABLE No. 13.

Summary of Color Studies on the Standard Roofing Tile Clays.

Designation of Clay.	Color Range.
A	Deep red, commercial grade—Cone 04–1.
B	Fine red, commercial grade—Cone 06–1.
C	Good red, commercial grade—Cone 02–3.
D	Good red, commercial grade—Cone 04–3.
E	Pink, salmon, buff, brown and blue-gray. Full of specks. Requires slip.
F	Pink, light red, brown and blue, with non-commercial red. Requires slip.
G	Good red, commercial grade—Cone 04 to 1.
H	Good red, commercial grade—Cone 04–2.
I	Yellowish red, poor red, chocolate and black. Not a good commercial grade. Requires slip.
J	Pinkish, buff, tan, brown and olive green. Would require slip.
K	Good red, commercial grade—Cone 06–2.
L	Poor lifeless red, barely commercial—Cone 06–1.
M	Good red, commercial grade—Cone 06–1.
N	Light red, buff, gray and yellow-brown. Would require slipping.
O	Good red, commercial grade—Cone 02–2.

It is somewhat astonishing to find that of twelve roofing tile plants, only eight were found to be working on good, clean, handsome, red-burning material. Three were working calcareous clays, which pass through a long cycle of color changes, without at any stage making a commercial red, and one plant mixes a clay of good, red-burning color, with two others, neither of which can pass muster, and the mixture resulting is a poor, lifeless, barely commercial red.

This is only another illustration of a fact well known in the clay industry, viz., that many plants are started by persons of little or no experience, and without expert advice, and after making heavy investments they find their clays unsuitable. Such concerns usually fail for their first projectors, but after one or more forced sales, at constantly reduced valuations, they ultimately fall into capable hands and are operated. The handicap of a poor or mediocre material remains, however, and is a constant bar to a really high grade product, or large financial success.

Color Range vs. Vitrification Range—A study of the vitrification range, as disclosed by the color changes, gives the following data:

TABLE No. 14.

Comparison Between Color Range and Vitrification Range.

Designation of Clay.	End of immaturity.	Period of maturity.	Period of over-maturity of color. Body still sound.	Point at which color goes black, and body fails also.	Remarks.
A	Cone 06..	Cone 04–1.	Cone 2–4.	Cone 5...	A fairly wide range.
B	Cone 08..	Cone 06–1.	Cone 2–4.	Cone 5...	A wide range.
C	Cone 04..	Cone 02–3.	Cone 4...	Cone 5...	A good range.
D	Cone 06..	Cone 04–3.	Cone 4...	Cone 5...	A good range.
E	Cone 02..	Cone 1–3.	Cone 4...	Not reached	Narrow range.
F	Cone 06..	Cone 04–02	Cone 1...	Cone 4...	Narrow range.
G	Cone 06..	Cone 04–1.	Cone 2–5.	Not reached	A fairly wide range.
H	Cone 06..	Cone 04–2.	Cone 3...	Cone 4...	A good range.
I	Cone 010.	Cone 08...	Cone 1–4.	Cone 5...	A wide range.
J	Cone 08..	Cone 06–1.	Cone 2–4.	Cone 5...	A wide range.
K	Cone 08..	Cone 06–2.	.....	Cone 3...	A wide range.
L	Cone 08..	Cone 06-1.	Cone 2–3.	Cone 4...	A good range.
M	Cone 07..	Cone 06–1.	Cone 2–5.	Not reached	A wide range.
N	Cone 08..	Cone 06–3.	Cone 3–4.	Cone 5...	A wide range.
O	Cone 04..	Cone 02–2.	Cone 3–4.	Cone 5...	Fair range

The foregoing table gives an illuminating view of roofing tile clays, and their variations, and enables us to fix a sort of tentative type for the group. So far as color changes are competent to decide, the type clay is as follows:

TABLE No. 15.

Color Scale of Typical Roofing Clay.

TINTS.	Range in Cones.
Immature and light red colors—Up to Cone 06	.....
Commercial-red Color Range—Cone 05 to Cone 1	5 Cones
Overmature Colors, red or brown, with body still sound—Cone 2 to Cone 4	3 Cones
Blue or Black Colors, with failure of body as well—Cone 5 and above	.....

The behavior of the four undesirable clays (not considering I, J, and K, which are not used individually in any plant and which appear in their proper proportions in Sample L) is difficult to summarize, because

they fail in a variety of ways. The foundation of the trouble of all, however, is the presence of enough lime to destroy or injure the red color.

Hardness.—The idea of hardness in the minds of most clay workers is associated with other concurrent physical properties which, strictly speaking, are not the same thing, though intimately related. The property of physical strength is involved in this common conception, and also the factor of toughness or brittleness. A clay worker in speaking of a tile would call it "too hard," without really meaning that the hardness itself is undesirable, but merely that its hardness leads him to expect it to be too brittle, and it is this quality he has in mind in condemning it.

Toughness, or its converse, brittleness, is a property not easily measured, except by rough comparative tests, such as the rattler test. As roofing tiles are never subjected in actual use to any influences tending to wear them out by friction or grinding, nor normally to impacts or blows, the application of the rattler test to this ware seems very foreign and inappropriate. Tests for hardness, as distinct from toughness or ability to resist blows, based on grinding the ware away by an abrasive plate or disc, under fixed conditions of pressure, lubrication with water, etc., have been proposed and carried out a few times by various investigators, but no standardized form of this test has come into acceptance.

The simplest, oldest and most universally practiced gauge of hardness is the cutting test—a mode so crude as to be practically impossible to standardize it, but so simple that, *for any one person*, its findings soon become satisfactory and convincing to himself. Nothing is required but a piece of hard steel, a knife or file, or similar tool, ground to a sharp but not thin edge. A triangular file, with all three surfaces ground into planes, makes the best tool. With this steel tempered as hard as it can be gotten, a man can soon gauge hardness in burnt clay wares, in terms that are not translatable into figures, but which are nevertheless satisfactory.

The test as carried out in this work was done by taking a sharp piece of file steel in the hand, as one would hold a glass cutter. Then with varying degrees of pressure from the hand, the tiles were easily scratched, barely scratched, or not scratched at all, or the steel left a blue metallic mark on the tile's surface. In the latter case, the tiles were classified as being harder than steel. Other trial pieces that could not be scratched, but failed to give a blue steel mark, were classified as steel-hard. After a little practice, these gradations could be determined without much difficulty.

In the following table, No. 16, is shown the data concerning the hardness of a series of samples of commercial roofiing tiles. In connection with the hardness, the percentage absorption is also shown:

TABLE No. 16.

Showing the Hardness of Some Commercial Tiles.

Designation of Sample.	Description of Resistance to Cutting.	Character of Fracture.	Percentage Absorption in 48 Hours.
A-1	Difficult to scratch	Stony	12.13
A-2	Difficult to scratch	Stony	13.89
B-1	Very difficult to scratch	Stony	6.22
B-2	Easily scratched	Porous and stony	20.03
B-3	Very difficult to scratch	Stony	8.43
B-4	Easily scratched	Porous and stony	20.63
C-1	Easily scratched	Stony	17.72
C-2	Easily scratched	Stony	13.35
D-1	Very difficult to scratch	Stony	5.82
D-2	Equal to steel	Semi-vitreous	3.26
E-1	Very difficult to scratch	Stony	5.92
F-1	Harder than steel	Vitreous	0.80
F-2	Equal to steel	Semi-vitreous	2.24
G-1	Equal to steel (Buff tile)	Stony	2.31
G-2	Harder than steel	Stony	1.73
H-1	Equal to steel (Buff tile)	Stony	7.61

In the following table, No. 17, pages 633-636, are shown the data on hardness as obtained from the experiments made on the standard roofing tile clays in the laboratory. They do not represent commercial wares:

TABLE No. 17.

Showing Comparative Hardness of Trial-pieces of the Standard Roofing Tile Clays.

CLAY A.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Easily scratched	010	Open, stony	29.53
2	Slightly harder than A-1	08	Dry, stony	25.77
3	Slightly harder than A-2	06	Dry, stony	18.11
4	Equal to steel	04	Semi-vitreous	11.52
5	Harder than steel } Best colors.	02	Semi-vitreous	7.48
6	Harder than steel } Best colors.	1	Semi-vitreous	4.95
7	Harder than steel	2	Semi-vitreous	3.00
8	Harder than steel	3	Semi-vitreous	2.51
9	Harder than steel	4	Semi-vitreous	1.08
10	Harder than steel (overfired)	5	Stony	1.23

CLAY B.

1	Scratched easily	010	Open grained	31.07
2	Scratched easily	08	Open grained	31.12
3	Difficult to scratch (Com. color)	06	Dry and stony	26.80
4	Very difficult to scratch	04	Dry and stony	25.76
5	Very difficult to scratch	02	Dry and stony	26.15
6	Barely possible to scratch	1	Stony	21.95
7	Equal to steel	2	Stony, very dense	19.29
8	Steel hard	3	Stony, very dense	12.57
9	Harder than steel	4	Vitreous	14.04
10	Harder than steel	5	Semi-vitreous	3.12

CLAY C.

1	Scratched very easily	010	Very open grained	35.94
2	Scratched very easily	08	Very open grained	35.02
3	Slightly harder	06	Very open grained	32.45
4	Difficult to scratch (Com. color)	04	Open, stony	17.00
5	Equal to steel	02	Dense, stony	14.30
6	Harder than steel	1	Semi-vitreous	7.41
7	Harder than steel	2	Vitreous	5.22
8	Harder than steel	3	Glassy	4.07
9	Harder than steel	4	Glassy	1.10
10	Harder than steel (overfired)	5	Stony	0.98

TABLE No. 17—Continued;

Showing Comparative Hardness of Trial-pieces of the Standard Roofing Tile Clays.

CLAY D.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Scratched very easily	010	Open grained	32.85
2	Scratched very easily	08	Open grained	32.03
3	Scratched very easily	06	Open grained	33.29
4	Difficult to scratch (good color)	04	Dense, stony	24.59
5	Nearly equal to steel (best color)	02	Semi-vitreous	13.04
6	Harder than steel (good color)	1	Semi-vitreous	12.62
7	Harder than steel	2	Semi-vitreous	10.12
8	Harder than steel	3	Semi-vitreous	2.62
9	Harder than steel (overfired)	4	Stony	0.74
10	Harder than steel (overfired)	5	Stony	0.80

CLAY E.

1	Scratched easily	010	Open grained	38.42
2	Slightly harder	08	Open grained	39.87
3	Slightly harder	06	Open grained	39.34
4	Slightly harder	04	Little more dense	41.67
5	Slightly harder	02	Little more dense	40.10
6	Equal to steel	1	Stony	12.50
7	Trifle under steel hard	2	Strong, but open	26.24
8	Harder than steel	3	Vitreous	1.90
9	Harder than steel	4	Vitreous	2.72
10	Harder than steel (overfired)	5	Stony	1.60

CLAY F.

1	Very easily scratched	010	Very open grained	33.99
2	Much harder	08	Very open grained	31.83
3	Much harder	06	Very open grained	33.48
4	Difficult to scratch	04	Dense, stony	23.65
5	Difficult to scratch	02	Dense, stony	24.61
6	Harder than steel	1	Vitreous	12.08
7	Harder than steel	2	Semi-vitreous	16.83
8	Harder than steel	3	Vitreous	2.93
9	Harder than steel (overfired)	4	Stony	0.60
10	Harder than steel (overfired)	5	Stony	1.24

CLAY G.

1	Very easily scratched	010	Very open grained	28.31
2	Very easily scratched	08	Very open grained	27.73
3	Nearly equal to steel (good color)	06	Stony	19.03
4	Nearly equal to steel } best color	04	Stony	16.19
5	Nearly equal to steel } best color	02	Stony	8.22
6	Harder than steel } best color	1	Semi-vitreous	9.10
7	Harder than steel	2	Vitreous	8.77
8	Harder than steel	3	Vitreous	8.42
9	Harder than steel	4	Vitreous	8.42
10	Harder than steel	5	Stony	7.82

TABLE No. 17—Continued.

Showing Comparative Hardness of Trial-pieces of the Standard Roofing Tile Clays.

CLAY H.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Easily scratched	010	Very open grained	30.96
2	Slightly harder	08	Very open grained	24.88
3	Same	06	Very open grained	29.94
4	Difficult to scratch (good color)	04	Dense, stony	24.95
5	Difficult to scratch (good color)	02	Dense, stony	25.37
6	Harder than steel, too dark	1	Semi-vitreous	8.03
7	Harder than steel, too dark	2	Semi-vitreous	16.20
8	Harder than steel, too dark	3	Vitreous	1.63
9	Harder than steel (overfired)	4	Stony	2.56
10	Harder than steel (overfired)	5	Stony	1.97

CLAY I.

1	Difficult to scratch	010	Open, stony	33.04
2	Difficult to scratch (best color)	08	Open, stony	33.33
3	Very difficult to scratch	06	Stony	32.10
4	Very difficult to scratch	04	Stony	32.17
5	Very difficult to scratch	02	Stony	32.10
6	Nearly equal to steel	1	Stony	29.62
7	Equal to steel	2	Stony	23.88
8	Steel hard	3	Semi-vitreous	17.94
9	Steel hard	4	Semi-vitreous	15.32
10	Steel hard (overfired)	5	Stony	0.52

CLAY J.

1	Difficult to scratch	010	Open grained	24.55
2	Difficult to scratch	08	Open grained	22.98
3	Nearly equal to steel } best color	06	Stony	11.22
4	Equal to steel } best color	04	Semi-vitreous	9.30
5	Equal to steel } best color	02	Semi-vitreous	9.15
6	Harder than steel	1	Vitreous	7.41
7	Harder than steel	2	Vitreous	7.17
8	Harder than steel	3	Vitreous	7.40
9	Harder than steel	4	Vitreous	7.88
10	Harder than steel (overfired)	5	Stony	9.21

CLAY K.

1	Difficult to scratch	010	Dry, earthy fracture	17.53
2	Difficult to scratch	08	Stony	14.48
3	Barely possible to scratch	06	Stony	8.24
4	Harder than steel	04	Semi-vitreous	5.77
5	Harder than steel	02	Vitreous	1.71
6	Harder than steel	1	Vitreous	0.65
7	Harder than steel	2	Semi-vitreous	0.80
8	Overfired	3	Spongy	.....
9	Overfired	4	Spongy	.....
10	Overfired	5	Spongy	.....

TABLE No. 17—Concluded.

Showing Comparative Hardness of Trial-pieces of the Standard Roofing Tile Clays.

CLAY L.

Designation of Trial-piece.	Description of Resistance to Cutting.	Temperature in Cones.	Character of Fracture.	Percentage Porosity.
1	Difficult to scratch	010	Stony, open grained	27.26
2	Difficult to scratch	08	Stony, open grained	24.82
3	Very difficult to scratch	06	Stony, open grained	22.59
4	Nearly equal to steel } best color	04	Stony, more dense	18.35
5	Nearly equal to steel } best color	02	Stony, more dense	15.50
6	Steel hard	1	Vitreous	15.63
7	Harder than steel	2	Vitreous	12.76
8	Harder than steel	3	Vitreous	10.55
9	Overburned	4	Stony	5.20
10	Overburned	5	Stony	4.45

CLAY M.

1	Easily scratched	010	Stony, open grained	29.88
2	Easily scratched	08	Stony, open grained	29.42
3	Difficult to scratch	06	Stony, more dense	28.49
4	Difficult to scratch	04	Stony, more dense	28.73
5	Difficult to scratch	02	Stony, more dense	27.74
6	Nearly equal to steel (best color)	1	Stony	21.73
7	Harder than steel	2	Glassy	10.73
8	Harder than steel	3	Vitreous	3.66
9	Harder than steel	4	Vitreous	3.10
10	Harder than steel	5	Stony	0.51

CLAY N.

1	Easily scratched	010	Open grained	37.12
2	Easily scratched	08	Open grained	38.25
3	Slightly harder	06	More dense	37.64
4	Same	04	Same	37.20
5	Same	02	Same	36.42
6	Nearly equal to steel	1	Stony	18.25
7	Nearly equal to steel	2	Stony	17.86
8	Harder than steel	3	Stony	5.68
9	Nearly equal to steel	4	Stony	21.04
10	Melted	5	Slaggy	1.01

CLAY O.

1	Easily scratched	010	Open grained	.....
2	Slightly harder	08	Open grained	.....
3	Much harder	06	Open grained	.....
4	Difficult to scratch	04	Becoming dense	.....
5	Very difficult to scratch	02	Very dense, but dry	.....
6	Equal to steel } best colors	1	Stony	.....
7	Equal to steel } best colors	2	Stony	.....
8	Harder than steel	3	Semi-vitreous	.....
9	Harder than steel	4	Semi-vitreous	.....
10	Harder than steel	5	Stony	.....

In order to obtain some judgment as to what degree of hardness in the foregoing tables represents a satisfactory roofing tile structure, we must be guided by the following considerations:

A tile should have a hardness sufficient to make it easily handled and shipped without chipping or easy breakage, and above all to resist any damage from frost. But a tile burned to a degree of extreme hardness is just as much at fault as one too soft-burned. In the former case, the tile has been carried to a degree of vitrification where it becomes vitreous and is brittle, and will withstand handling, shipping, and cutting at the roof very poorly and large losses will result. Also, what has been said earlier in this report under the heading of "Porous vs. Vitrified Tile" applies to the hardness also. That is, a tile that has been burned to a degree of hardness such that it is vitreous, will not prove as satisfactory upon the roof as a medium hard one. The extremely hard tiles will sweat, owing to their inability to absorb the moisture condensed upon their under surfaces.

While the foregoing method of testing the hardness of the various commercial tiles and the vitrification trial pieces was very crude, it has shown one point quite clearly, viz., that the best commercial colors of the clays are found to correspond quite closely to the hardness of steel or a trifle below. The moment the trial piece becomes harder than steel, the fracture appears vitreous, and the color in most cases becomes too dark. These latter tile would be too hard for economy in commercial handling. In the light of the foregoing data and discussion, we may say that the hardness phenomena of the typical roofing tile clay will be about as follows:

TABLE No. 18.

Range of Hardness of Typical Roofing Tile Clay.

Cone.	Hardness Data.	Commercial Grade.
010	Generally soft and easily cut	Too soft.
08	Generally soft and easily cut	Too soft.
06	Difficultly cut	Generally too soft.
04	Very difficultly cut	Generally good.
02	Steel hard	Prime.
1	Harder than steel	Getting too hard.
2	Harder than steel	Too hard.
3	Harder than steel	Too hard.
4	Harder than steel	Overfired.
5	Harder than steel	Overfired.

Hardness vs. Vitrification Range.—In order to reduce the foregoing mass of data to a more compact form, for the purpose of drawing

conclusions more easily, the following symbols were used in the following table:

Degree of Hardness	Symbol
Very easily scratched	½
Easily scratched	1
Difficultly scratched	2
Very difficultly scratched	3
Equal to steel	4
Harder than steel	5

Assembling the data in this form, we have:

TABLE No. 19.

Hardness as a Gauge of the Vitrification Range.

Cone	Clay Samples.														
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
010	1	1	½	½	1	½	½	1	2	2	2	2	1	1	1
08	2	1	1	½	1	1	1	1	2	2	2	2	1	1	1
06	2	2	1	1	2	1	3	1	3	3	3	3	2	2	2
04	4	3	2	2	2	2	3	2	3	4	5	3	2	2	2
02	5	3	4	3	2	2	3	2	3	4	5	3	2	2	3
1	5	3	5	5	4	5	5	5	3	5	5	4	3	3	4
2	5	4	5	5	3	5	5	5	4	5	5	5	5	3	4
3	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5
4	5	5	5	5	5	5	5	5	4	5	5	5	5	3	5
5	5	5	5	5	5	5	5	5	4	5	5	5	5	–	5

The heavy line has been drawn in the preceding table at a point supposed to represent the transition of the clay from the stage where it can barely be cut, to the steel-hard stage. This particular hardness cannot be correlated with either the beginning of commercial grades or the end of them. It is likely to represent the middle of the valuable period of the clay's life—not too soft to stand weather, nor so hard as to be brittle and glassy.

It will be seen that clays I and N, both of which are poor materials, high in lime and of bad color, show a slow or gradual hardening, and have a different vitrification habit from the other clays. Aside from these two clays, the line clings closely to the temperature zone 04-02-1.

It is not possible to show the *range* of the vitrification process by hardness data, as well as by color or other tests, for no change of hard-

ness occurs to mark the condition of overfire, until the latter becomes excessive.

Porosity—The vitrification process in clays is most accurately marked by the changes in porosity of the sample. Vitrification means the assumption of a dense condition by a body originally always porous and sponge-like in structure. The vitrified body may or may not be vitreous, or glass-like. It may even be still notably porous, at the stage where it attains the best approach to a dense, vitreous structure that it is able to make at any temperature. Some clays never do vitrify to any satisfactory degree, but after gaining strength, hardness and density to only a moderate degree, they begin to undergo the bloating and destructive changes of overfire.

Vitrification is brought about by partial fusion of the mass, or rather the progressive fusion of portions of the mass and the attack on the still solid remainder by this fluid magma. As the fusion proceeds, the spaces between the original grains fill up and are obliterated, and if carried to the extreme of perfect fusion, the mass would become like a glass, entirely solid and devoid of recognizable pores.

Since clay wares are not fused and cast in moulds, as glass or metal is, but are moulded while plastic with water, and merely carried up to such hardening as is safe without loss of shape by fusion, it follows that the initial structure of the mass is always preserved to some extent, and the voids between the grains, which constitute from 30 to 40 per cent. of the volume of the clay at the end of the dehydration and oxidation process, are never fully closed up. Consequently, all clay wares are somewhat porous, or rather they contain cavities filled with air or gases. But the voids are inter-communicating in the beginning; the clay is *porous* in the real sense of the word, and fluids or gases will permeate it freely. But as vitrification progresses, the communication between voids becomes less and less perfect, and when the process is complete, in the sense of having reached the best combination of qualities that the clay can produce, these voids usually communicate to only a very limited degree. They are mostly present now as gas-blebs or sealed cavities, and are not properly pores at all. A clay burnt to this stage is not able to absorb much if any water, because the cavities inside do not reach the surface.

The extent to which the porosity of a given clay will be extinguished under heat treatment will be dependent upon many factors—the mineralogical composition of the clay, the size of its grains, and their proportions, and the intimacy of the mixture are prominent factors. For instance, calcium carbonate, if finely ground and evenly distributed throughout a clay mass in not too large proportion, will cause early and very rapid fusion of the body, but, should a like quantity of the same material be added in coarse, granular, or lump form, it will have but very little effect upon the mass, and combination will occur only

at the points of contact. The rate at which the heat is applied, the pressure on the mass, and the chemical condition of the fire gases, also affect the rate of vitrification profoundly.

In a study of all the changes that occur in the burning of a clay, there is no single factor that will explain what has taken place as well as a close study of the porosity changes. From these may be detected very clearly, not only the rate of the vitrification process as a whole, but also the periods of rapid or slow action, and the point where the failure of the mass begins. From what may be learned from the porosity curve, very safe conclusions can be drawn as to the suitability of a given clay for manufacture, so far as its vitrification behavior is concerned.

The percentage porosity expresses the relation between the volume of pore space and the combined volume of the particles of which the clay is composed. It is, in other words, the ratio of the void spaces to solid particles.

Dr. E. R. Buckley[1] gives the following formula for determining porosity:

$$100 \frac{(W - D)\ \text{Sp. gr.}}{(W - D)\ \text{Sp. gr.} + D} = \text{per. cent. porosity.}$$

W = saturated weight.
D = dry weight.
Sp. gr. = The composite specific gravity of the clay particles, as calculated from the dry, saturated, and suspended weights of the trial pieces.

Purdy[2] has simplified the formula of Dr. Buckley to the expression:

$$100 \frac{W - D}{W - S} = \text{Porosity.}$$

The Purdy formula was used in this work.

The trial pieces for this measurement of porosity were obtained by breaking the one inch by one inch by six inch vitrification trial pieces in two. These pieces were carefully dried on a hot plate to constant weight; then, without allowing time to absorb water from the atmosphere, they were weighed on a chemical balance, accurate to one-hundredth of a gram.

Each trial piece was then immersed in distilled water, with one end slightly exposed to allow easy escape of the air. At the end of 24 to 30 hours, they were placed under a bell-jar and the air kept exhausted for a period of about 4 hours, it having been found necessary to hold

[1]Wisconsin Geol. and Natural History Survey, Bull. VII, Econ. Series 4, p. 20.

[2]Purdy, R. C. Illinois Geological Survey, Bull. 9, p. 142.

them under vacuum for that length of time to bring out the last traces of gases that would come out of the interior voids.

After this treatment, the trial pieces were suspended, one at a time, by means of a silk thread, from the beam of a chemical balance and their saturated weights taken. While still suspended by the thread, a beaker partly filled with distilled water was brought up from below, so that the briquette was immersed in water and could still swing clear from the sides of the beaker. Thus the suspended weight of each trial piece was taken.

These three determinations, applied in the formula before quoted, gave the porosity in per cents. These figures were obtained on each trial piece, representing each temperature at which draws were made, from the standard list of roofing tile clays.

TABLE No. 20.

Showing Porosity of the Standard Roofing Tile Clays, Fired to Different Stages of Vitrification.

Designation of Clay.	Heat Treatment Expressed in Cones.									
	010	08	06	04	02	1	2	3	4	5
A	29.53	25.77	18.11	11.52	7.48	4.95	3.00	2.51	1.08	1.23
B	31.07	31.12	26.80	25.76	26.15	21.92	19.29	12.57	14.04	3.12
C	35.94	35.02	32.45	17.00	14.30	7.41	5.22	4.07	1.10	0.98
D	32.85	32.08	33.39	24.59	13.04	12.62	10.12	2.62	0.74	0.80
E	38.42	39.87	39.34	41.67	40.10	12.50	26.46	1.90	2.72	1.33
F	33.99	31.83	33.48	23.65	24.61	12.08	16.83	2.93	0.60	1.24
G	28.31	27.73	19.03	16.19	16.69	8.22	9.10	8.77	8.42	7.82
H	30.96	24.88	29.94	24.95	25.37	8.05	16.20	1.65	2.56	1.97
I	33.04	33.33	32.10	32.17	32.10	29.62	23.88	17.94	15.32	0.52
J	24.55	22.98	11.22	9.30	9.15	7.41	7.17	7.40	7.88	9.21
K	17.53	14.48	8.24	5.77	1.71	0.65	0.80	Bloa	ted	. . . .
L	27.26	24.82	22.59	18.35	15.50	15.63	12.76	10.55	5.20	4.45
M	29.88	29.42	28.49	28.73	27.74	21.43	10.73	3.66	3.10	0.51
N	37.12	38.25	37.64	37.20	36.42	18.25	17.86	5.68	21.04	1.01
O	27.31	32.23	29.04	22.85	20.04	8.84	11.74	7.31	3.92	5.35

Analysis of the Porosity Data—In order to facilitate the reading and meaning of the data in the preceding table, an effort has been made to classify the clays shown into three different groups and to depict by curves the percentage porosity of the clays of each group.

Group 1. This group is of exceedingly narrow vitrification range. It comprises clays E, N, M and H. In none of this group do any serious or significant porosity changes occur prior to cone 02, but immediately following that point the porosity drops very rapidly until, at cone 3, vitrification is practically complete and no further diminution of porosity occurs with further accessions of heat (Figure 26). This signifies that the vitrification process or the mutual solution of the minerals

of the clay does not begin early, but that it proceeds with great vigor when once begun. They indicate also that if the burning process is interrupted at a point between cones 02 and 3, that the tiles in the kiln would be apt to show a very irregular degree of porosity, for in no

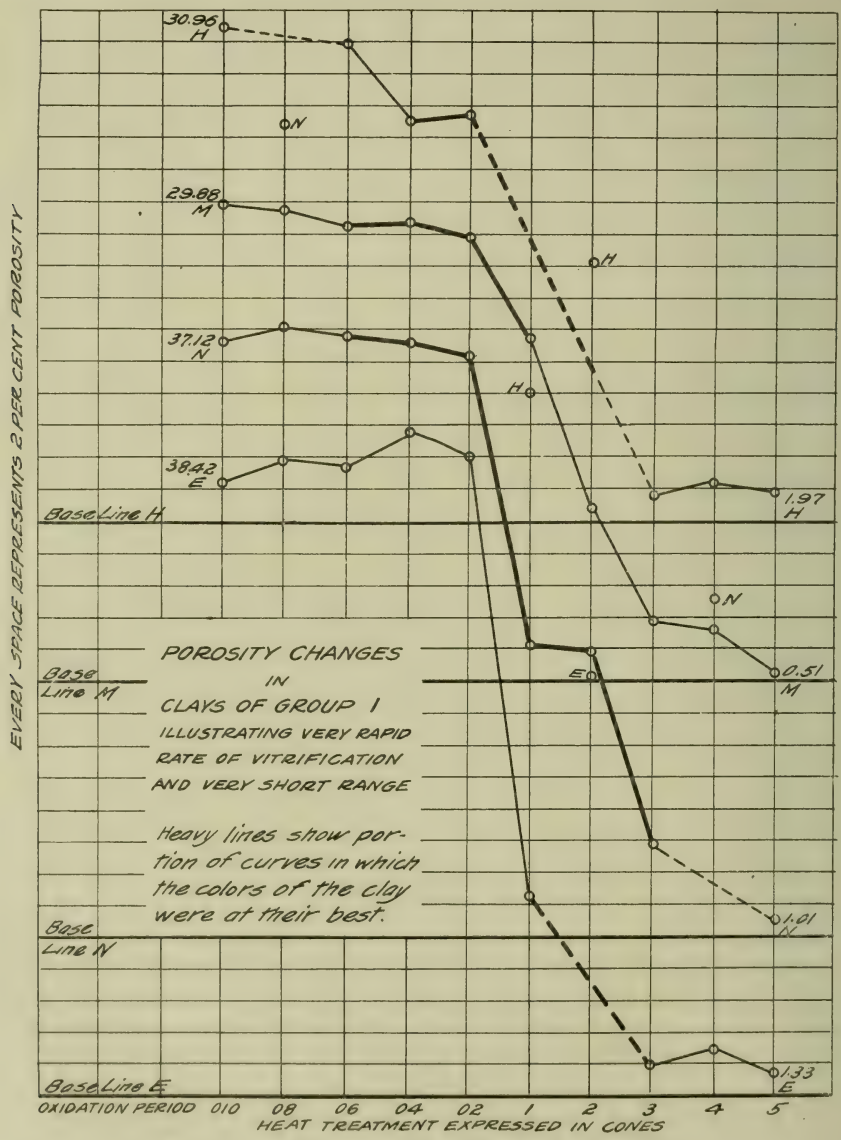


Fig. 26—Porosity Changes in Clays of Group I.

ordinary kiln-burning of such wares is the entire kiln likely to fall within a range of one cone in temperature. But in the four clays cited, one cone in temperature stands for a large reduction in porosity, so that with ordinary variations of kiln temperature we should have great variations in vitrification.

In the following table are shown the facts as to the porosity changes per cone for clays composing this group:

TABLE No. 21.

Porosity Changes per Cone in Group I.

Designation of Clay.	Temperature Range.	Number of Cone Intervals.	Reduction in Porosity Per cents.	Reduction in Porosity Per Cone.
E	02–3	4	38.20	9.55
N	02–3	4	30.74	7.68
M	02–3	4	24.08	6.02
H	02–3	4	23.72	5.93

The facts shown in this table constitute a serious indictment against these clays, of course. If the ware were of a sort that permitted selling in a wide variety of hardness, as common bricks do, so that the kilns need not be raised above cone 02, or if the ware could be kept in shape well at temperatures exceeding cone 3, so that all of the kiln could be brought to that point, constant physical structure in the product, so far as porosity is concerned, would be expected.

The color-temperature range has been indicated on these curves for the purpose of showing in what portion of the burn the colors are most satisfactory. We find considerable variations, but in three of these four clays, the colors are as good as the clays respectively can generate for a period preceding active vitrification. If the kilns could be finished off at these temperatures, then the burning would be relatively easy. But, the porosity being still almost unaffected, the wares would be altogether too soft for use. Later, when the clay has shrunk and become dense and hard, the color is no longer suitable for roofing tiles. In the case of clays N and E, both are calcareous, buff-burning materials and would require slipping at any temperature to get a marketable color.

It should be noted that three erratic determinations have been rejected in drawing these curves. The determinations are plotted, with the clay that they belong to marked beside them, but they seem so certain to be due to some discrepancy in weighing, or recording, or to uneven heat distribution in the test kiln, that they have not been considered in the above remarks or the curves.

Group II.—This group comprises clays of moderate vitrification range and rate. It includes clays A, C, D, F and O. There are several determinations here also that seem unduly erratic, especially clay F at cones 02 and 2, and clay O at cones 010 and 1. They have been plotted, but the curves have been drawn with allowances or corrections in accordance with the preponderance of the data. (See Figure 27.)

These clays differ from the first group in three respects. First, they do not delay so long in beginning to undergo important porosity changes. At cone 08, in all but clay O, and at cone 06 in the latter, the vitrification process is evidently busy at work. Second, they do not progress at nearly so rapid a rate, as they are not down to minimum porosity till cone 4 is reached. This shows a complete vitrification range of eleven cones, or approximately 220° C., as against four cones for group one.

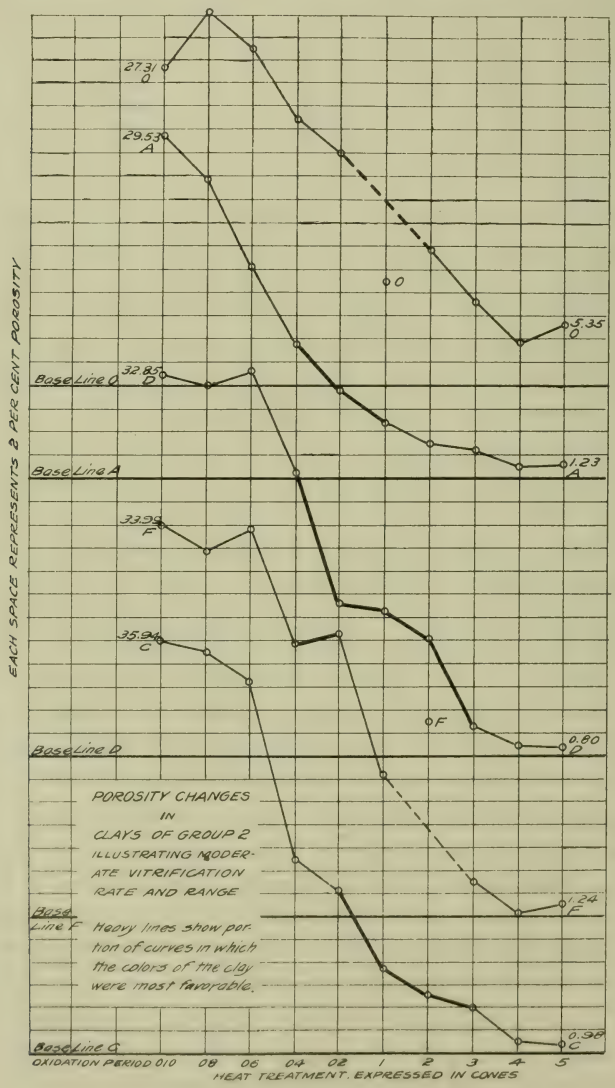


Fig. 27—Porosity Changes in Clays of Group II

The average reduction of porosity per cent. per cone in this group, between cones 08 and 4, is about 2.70%. In the following table are shown

the facts as to the clays composing this group, in the zone of their most rapid vitrification:

TABLE No. 22.

Porosity Changes per Cone in Group II.

Designation of Clay.	Temperature Range.	Number of Cone Intervals.	Reduction of of Porosity Per cents.	Reduction of of Porosity Per Cone.
C	06–1	6	25.04	4.17
F	06–1	6	21.40	3.56
D	06–1	6	20.77	3.46
A	08–02	6	18.29	3.05
O	06–1	6	20.20	3.36

The reduction in porosity, in the most rapid part of the process, over a range of 6 cones is much lower than in 4 cones in Group No. 1. If the entire vitrification range of these clays (instead of the most rapid part only) were included, it would show a still more striking contrast.

Third, the period of good color occurs after vitrification is relatively well advanced—much later than clays H and M in Group No. 1. There is a chance, therefore, to get these clays finished off during a period of relatively slow vitrification change, which is essential to safe and profitable burning.

Group III.—These are clays of slow vitrification rate and wide range. This group comprises clays B, G and L. Clays I, J and K, which are blended to produce L, are not given a separate position, because none of them are by themselves used for roofing tile manufacture.

The clays of Group No. 3 show three erratic determinations, two in clay L, at cone 02 and 1, and one in clay B at cone 4. These determinations have been plotted, but not drawn into the curves. They are probably due to experimental errors, very likely in irregular heat distribution in the test kiln. (See Figure 28.)

This group is characterized by a continuous and gradual reduction of porosity from cone 010, when the first draw-trials were taken, to cone 5, when the last was taken, and none of them were yet as dense as many clays become. Their average drop in per cent. absorption per cone, over the range in which vitrification is in progress, is about 1.7% over the whole zone. Clay B belongs to this group with less certainty than the others. It might be graded in Group No. 1 nearly as well.

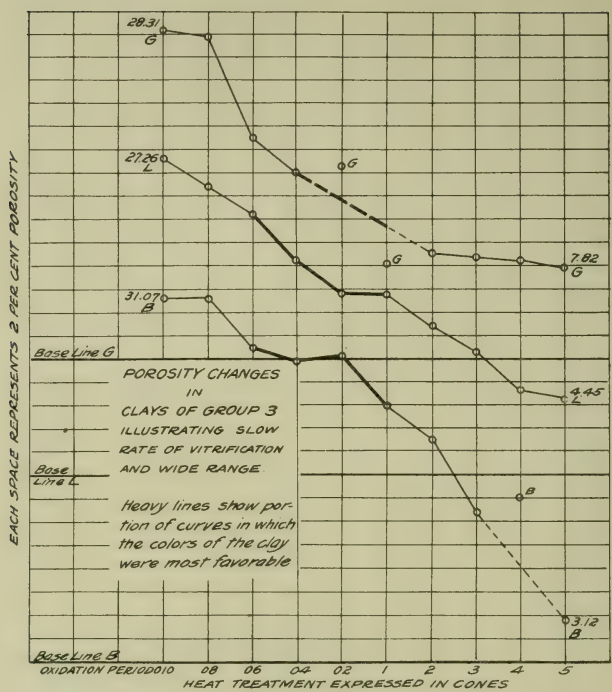


Fig. 28—Porosity Changes in Clays of Group III.

In table No. 23, the porosity changes per cone are contrasted·

TABLE No. 23.

Porosity Changes per Cone in Group III.

Designation of Clay.	Temperature Range.	Number of Cones Interval.	Reduction in Porosity Per cents.	Reduction in Porosity Per Cone.
B	04–1	6	13.58	2.26
G	08–02	6	11.54	1.92
L	010–04	6	8.91	1.48

The zone of commercial color is seen to occur in the middle of the vitrification process, but with changes progressing so slowly that it should be possible to fire a kiln off with fairly uniform color throughout.

The clays of this group have an undoubted advantage over both preceding groups, so far as the evidence of the porosity changes is concerned. If satisfactory in other respects, they should be very safe in the kiln.

For purposes of comparison, the following curve-sheet (Figure 29) containing clays I, J, K and the body blended from them, L, has been prepared. It is to be observed that clay K, which is the basis of the mixture,

has a very steady vitrification process, coming to completion at cone 02, and bloating badly if overfired beyond cone 2. This clay has evidently begun to vitrify well before cone 010, as the porosity at cone 010 is only 17.53%, which is too low for any clay in its period of maximum openness of structure.

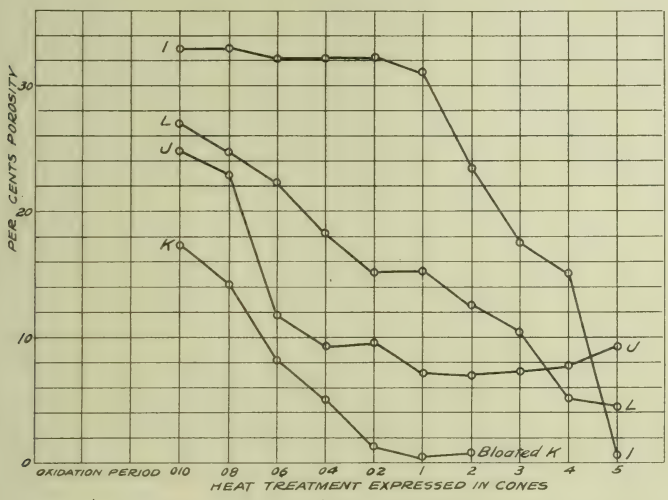


Fig. 29—Porosity Changes per Cone in Clays I, J, K and L.

To this regular but very early vitrifying clay are added I, a clay clearly belonging to Group No. 1, which vitrifies hardly at all until cone 1, and clay J, which vitrifies rapidly at cone 06, and thereafter changes little in the temperature limits tested, but which reaches only a very imperfect vitrification at best.

L, the mixture or composite clay, shows beautifully the influence of these components. Its course is parallel to clay K, but its progress is much delayed, so that when clay K is fully vitrified and ready to swell from overfire, clay L has still 12.75% porosity, and this is not wholly eliminated by going to cone 5, though the body becomes undesirable for roofing tile long before that point.

In view of the fact that clay K has a good color by itself and apparently a good, though very early vitrification behavior, it would appear that the addition of clays I and J to it, spoiling not only its color but its vitrification behavior as well, is unfortunate. The occurrence of the three clays in the mine would make it difficult and expensive to mine clay K without also mining I and J, which is the reason for their inclusion in the mixture.

Summary on Porosity Changes.—The grouping of the twelve roofing tile clays into three more or less clearly defined groups on the strength of their porosity curves is not, however, a conclusive or satisfactory decision as to their quality. Good clays and bad ones, judged by other and not less important criteria, are found both in and out of each group.

Considering the clays in two groups—those of good color and those of bad—and listing the porosity data opposite each we have:

TABLE No. 24.

Comparison of Color Range and Porosity Behavior.

Designation of Clay.		Character of Porosity Curve.
A	Clays of good commercial color range.	Wide vitrification range. Slow changes. Process complete at cone 3.
B		Wide vitrification range. Slow changes. Process complete at cone 5.
C		Rather narrow range. Rapid changes between cone 06 and 04. Moderate between 02 and 3, in zone of useful colors. Complete at cone 4.
D		Rather narrow range. Rapid changes between 06 and 02. Complete at cone 3–4.
G		Wide range. Changes slow. Process incomplete at cone 5.
H		Narrow range. Sudden changes between cones 02 and 1. Changes complete at cone 3.
M		Narrow range. Sudden changes between 02 and 3. Finishes process at cone 5.
O		Fairly wide range. Changes steady and not rapid. Changes incomplete at cone 5.
E	Bad colors.	Very narrow range. Rapid changes between 02 and 3. Complete at cone 3.
F		Rather broad range. Erratic. Most rapid changes between cones 02 and 1. Finishes process at cones 3 and 4.
L		Very wide range. Slow processes, incomplete at cone 5.
N		Very narrow range. Changes very rapid between cone 02 and 3. Vitrification complete at cone 5.

Thus we have six clays whose vitrification range is good; four of these have good color, while two are of poor colors, though not the worst. On the other hand, we have six clays whose vitrification range is narrow. Of these, four have good colors, while two have colors entirely unfit for use without slipping.

In view of these facts, it can hardly be claimed that a typical roofing tile clay can be set forth, judged on the basis of its porosity changes.

Porosity vs. Vitrification Range.—While the definition of a type clay is not possible from the foregoing evidence, it is not so difficult to construct an ideal of what the porosity changes should be to constitute

a desirable clay from the standpoint of safe burning. Suppose the clay in question is to reach complete maturity of color at cone 1. The following may be taken as a desirable porosity behavior.

TABLE No. 25.

Relation Between Porosity Behavior and Color, in Ideal Roofing Tile Clay.

Temperature Expressed in Cones.	Porosity Expressed in Per cents.	Color-Sequence and Structure.
Below 010	.. to 30	Light yellow or pinkish reds—not commercial. Structure very porous.
010	30 to 26	
08	26 to 18	
06	18 to 10	Commercial red colors, ranging from light to dark. Structure, sufficiently dense.
04	10 to 6	
02	6 to 4.5	
1	4.5 to 3	
2	3 to 2	Colors too dark. Body at greatest density.
3	2 to 3	
4	3 to 4	Colors entirely overdone. Body beginning to swell from overfire.
5	4 to 6	

Whether any given clay reaches its maturity at the temperature limits indicated above, is not so important as that the general shape of the porosity curve should be substantially as shown. Its most rapid changes should occur before the development of the best commercial colors; then a period of good colors and relatively small porosity changes, merging into a zone of darker colors, and still less body change, and finally destruction of marketable colors and the increase of porosity from the swelling of the body.

Specific Gravity—Until recently the specific gravity, while frequently determined, has yielded little if any intelligent insight into the clay's qualities. It was found that *per se* the specific gravity of a clay did not clearly indicate anything, pro or con. It remained for Purdy[1] to make the first effective use of this determination, which he did by determining the specific gravity of clays at a series of stages of burning, and also by adopting precautions to get the real, as well as the apparent specific gravity. In his hands, this determination has been useful in analyzing the processes taking place in the vitrification of clays, and he has reinforced the evidence obtained from the porosity and shrinkage studies. It has been of special importance in bringing out and demonstrating the amount and volume of the sealed pores in vitrified clay bodies, the existence of which could not be proved by absorption or porosity measurements.

[1]R. C. Purdy, Illinois Geol. Survey, Bull. IX, p. 133.

Method of Determination.—The formula by which the apparent specific gravity of a lump of any substance is obtained is $\frac{D}{D-S}$ in which D = the dry weight of the substance and S = the weight of the same substance suspended in water.

The true specific gravity is determined from the powdered material, ground so fine as to make the existence of any sealed pores or gas cavities in the grains a matter of some improbability. This determination is made in a small flask, accurately standardized, and called a pycnometer.

In the work done in this report, no effort was made to pursue these investigations to the refinement that has been shown in the work of Purdy[1], which should be consulted for further details on the capabilities of this mode of research. The determinations were made by the simplest process and represent the apparent specific gravity only.

The same test pieces used in the porosity test were used, and the same weights. The porosity data being at hand, a mere calculation suffices to obtain the apparent specific gravity and for this reason it has been deduced and tabulated. (See page 651.)

Examining the data of the foregoing table, it may be observed that in every instance the changes in value run along with small variations from low to higher temperatures, until finally a sudden or marked drop occurs. The point where the drop occurs is as early as cone 04 in the case of clay K, while it only occurs at cone 5 in five other samples.

The significance of this break in the figures of each clay is as follows: While the clay remains porous or only partially vitrified, its voids are very largely permeable by water, especially if resort be had to boiling or the vacuum pump to suck out the air and allow the liquid to take its place. Hence calculation, as per the formula above, gives a close approximation to the true specific gravity. But, when the fusion progresses to the point of sealing up the voids, or creating new blebs, from the evolution of gases inside the sticky, glassy matrix, then a determination of the specific gravity of the lump gives results too low, for the gases are only very imperfectly replaced by water, and the denominator of the fraction $\frac{D}{D-S}$ becomes too large, owing to the increased displacement of the swollen lump, without proportionately increased weight. If the mass continued permeable to water, then the value of D — S would remain constant, whatever its volume.

The reduction of the apparent specific gravity of the trial pieces indicates, therefore, the growth of sealed blebs or cavities, and this in turn indicates progress towards a pasty, sticky stage of vitrification or semi-fusion. A clay is therefore certainly deteriorating in structure when its apparent specific gravity grows markedly less.

[1]Loc. cit.

TABLE No. 26.

Showing Changes in Specific Gravity of the Standard Roofing Tile Clays at Different Stages of Burning.

Designation of Clay.	Temperature Expressed in Cones.									
	010	08	06	04	02	1	2	3	4	5
A	2.54	2.52	2.45	2.52	2.48	2.46	2.42	2.41	2.25	2.23
B	2.66	2.67	2.68	2.68	2.68	2.70	2.61	2.57	2.56	2.35
C	2.63	2.66	2.64	2.56	2.55	2.50	2.49	2.45	2.30	2.26
D	2.54	2.58	2.63	2.58	2.60	2.50	2.47	2.40	2.28	2.20
E	2.63	2.75	2.73	2.76	2.62	2.51	2.60	2.39	2.05	1.60
F	2.58	2.56	2.63	2.56	2.56	2.71	2.53	2.34	2.06	2.04
G	2.68	2.69	2.68	2.67	2.57	2.62	2.53	2.54	2.51	2.35
H	2.60	2.58	2.55	2.58	2.52	2.42	2.50	2.32	1.93	1.73
I	2.67	2.67	2.64	2.64	2.63	2.55	2.55	2.45	2.44	1.93
J	2.56	2.55	2.50	2.50	2.49	2.43	2.39	2.39	2.39	1.96
K	2.46	2.46	2.44	2.44	2.34	1.88	2.00	.....	.....	.....
L	2.61	2.54	2.62	2.59	2.63	2.51	2.35	2.27	1.15	1.20
M	2.56	2.57	2.67	2.66	2.62	2.62	2.50	2.44	2.41	2.21
N	2.64	2.70	2.68	2.67	2.66	2.43	2.44	2.36	2.46	2.02
O	2.50	2.53	2.52	2.50	2.48	2.45	2.45	2.44	2.42	2.13

Judged by this standard, the clays pass the line from a reasonably sound structure into a rapidly failing stage at the point indicated in the table by a heavy black line in each horizontal column.

Comparing these determinations of the failing point of the clay with those obtained from the porosity test, we find that the specific gravity indicates a clay as failing earlier than by the latter, often several cones earlier and usually at least one. There are, however, wide variations in the extent of the indicated failure, and these are much more easily recognized by means of curves.

For convenience, the clays are drawn on curve sheets (Figure 30) in the order of their reduction in specific gravity, from the maximum to the minimum of each clay. Thus clay A changes only 0.31 between its maximum and minimum, showing that at cone 5 viscous swelling, or

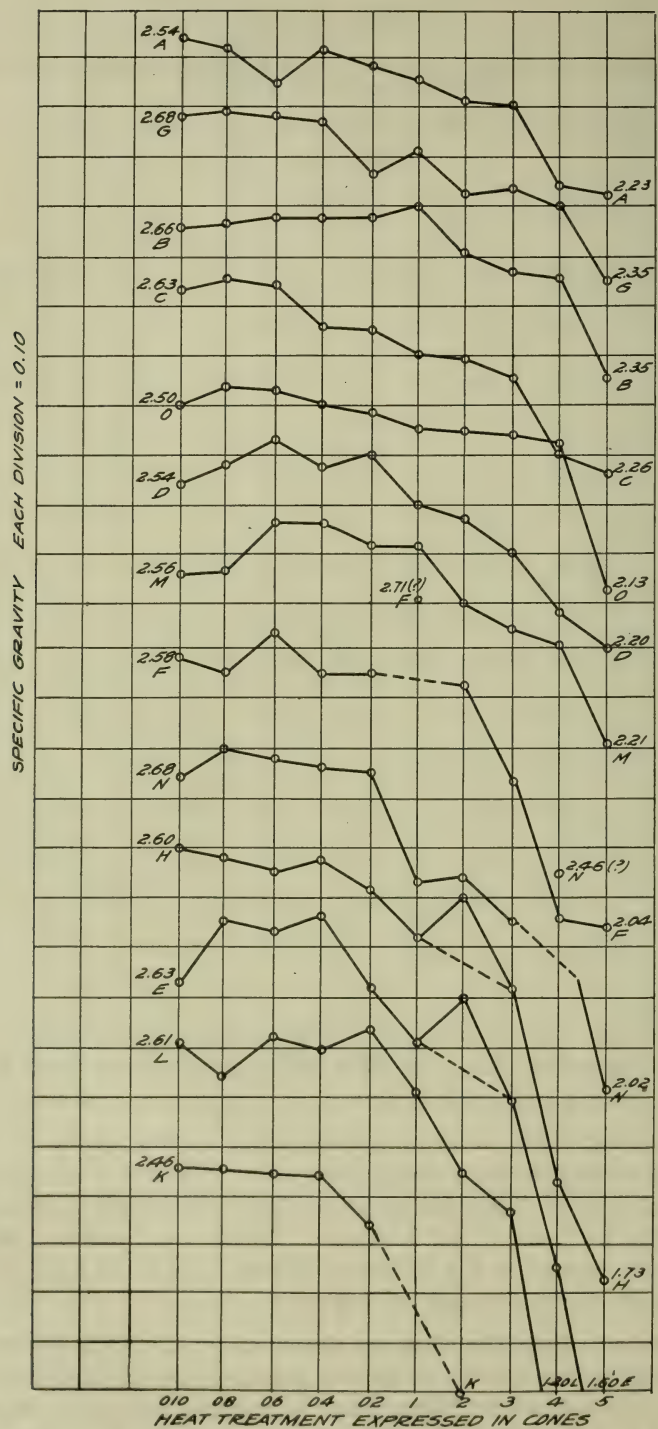


Fig. 30—Curves Showing Changes in Specific Gravity of the Standard Roofing Tile Clays at Various Stages of Heat Treatment.

development of sealed gas blebs, had progressed to a small extent only. Clay L, on the other hand, changed 1.48 in specific gravity in the same heat treatment, showing the clay was far gone in viscous bloating. No effort has been made to group these clays according to the actual numerical value of their specific g avity, as this is a function of their mineral composition. It will be noted that the bad, limy clays E and N both show exceptionally high specific gravity, 2.76 and 2.70 respectively.

A study of these curves shows a very considerable variety in their details, but the tendency is for each clay to attain a maximum, somewhere prior to cone 02, and thereafter fall away more or less sharply, as the sealed pores begin to affect the volume.

Clays A, G, B, C, O, D and M all have curves in which the reduction is moderate in amount, and occurs late enough in the firing, to show that these clays have wide vitrification ranges and safe vitrification habit. Clays F, N, H, E, L and K all show curves in which the reduction is large in amount and rapid in rate, and indicate clays of unsafe vitrification habit.

It will be noted that the clays which are condemned in the color test, E, F, L and N, are all condemned by this specific gravity test also, and with them clay H, whose color is good.

No standard of specific gravity for roofing tile clays, either in numerical amount or in rate of change, can be set as the result of this inquiry, but in comparison of other clays with these, a similarity of general contour with the clays here known to be of good working quality, would tend to confirm other sources of judgment.

Total Shrinkage.—The total shrinkage is a property of much concern to the roofing tile manufacturer. Of the total shrinkage which occurs between the moulding of the plastic clay and its recovery from the kiln, that part of the change in volume which occurs in burning is of more vital importance. Proper pallets and forms can be made to hold a piece of clay straight and true while drying, but such devices, while possible in the burning, are too costly for wares which sell as cheap as roofing tiles. In an earlier part of this chapter, the drying shrinkage has been discussed in detail, and there now remains to consider the shrinkage in burning.

A knowledge of the total shrinkage of a clay has a direct practical application, as it furnishes the information necessary to construct dies and moulds of the proper size to make a piece of ware that will, when burned, have the proper size and dimensions.

In order to obtain the correct total shrinkage for practical purposes it is, of course, necessary to grind the clay to the proper fineness, temper with the right amount of water and burn to the temperature required in the actual manufacture of the ware.

The cause of the shrinkage of the clay is the same as the force which extinguishes the porosity and converts a spongy, cellular mass, full of voids, into a dense resistant solid that steel will not cut nor weather crumble. The vitrification or interaction of the minerals, and their mutual solvent effect on each other at high temperatures, causes the particles composing the old mass to disappear and the spaces between to close up. This produces a shrinkage, which is usually greater in proportion as this action is more complete.

But there is another force which tends to counteract this shrinking tendency, which has been discussed in connection with porosity and specific gravity studies. This is the tendency to form gas blebs or bubbles in the mass, which, unable to escape, swell as the temperature increases and tend to convert the clay into a cindery or frothy slag. These two processes are working against each other during vitrification. The shrinkage is more powerful for a time, and the clay grows less in volume in spite of the thousands of minute gas cavities that are forming. But after a time, the swelling action is the more powerful, and then the shrunken clay begins to bloat, and may assume its initial size or even become much larger than it ever was.

The causes of this swelling and the conditions and mineral com position which especially favor its development will not be discussed at greater length at this time. It is merely necessary to point out that if the shrinkages of a series of test pieces fired to progressively higher temperatures be measured and plotted on a curve, we will find that in nearly every clay the curve rises with the temperature for a time, sometimes at a uniform gradual rate, and sometimes very suddenly, and then after reaching a maximum, it usually stands more or less constant in volume for a time, the shrinkage and bloating reactions being in a deadlock so to speak, and then the bloating triumphs and the volume increases again.

The determination of the shrinkage in the test of the standard series of roofing tile clays was on the same series of test pieces which had been measured for the determination of the drying shrinkage. The methods of firing, drawing, cooling, etc., were as described in connection with the preceding tests for color, hardness, etc. The results are shown in table No. 27, page 655.

In order to get the assistance of the graphic method, the data of the above table were plotted in a series of curves, excluding that from clays I, J and K, which are represented in their blend or mixture, clay L, but which have no separate use for roofing tiles (Figure 31). In plotting the above curves, efforts to divide up the clays into groups of similar behavior were not satisfactory or illuminating. Each clay has therefore been plotted singly, though arranged in the order of decreasing total shrinkage value, viz., clay O with 14.00 per cent. is first, clay C with 13.60 per cent. is second, etc., The beginning and ending of each curve is

TABLE No. 27.

Showing Total Linear Shrinkage of Standard Series of Roofing Tile Clays.

Designation of Clay.	Heat Treatment Expressed in Cones.									
	010	08	06	04	02	1	2	3	4	5
A	4.90	6.00	6.60	9.90	10.90	11.80	12.20	11.60	11.90	11.00
B	3.00	3.25	5.00	5.00	5.00	5.75	7.00	7.00	8.00	7.50
C	4.60	6.30	6.70	10.50	11.90	13.50	13.50	13.20	13.60	13.30
D	3.10	3.30	2.90	7.00	7.30	11.20	11.60	13.00	13.20	12.60
E	6.00	4.60	4.90	6.20	5.60	10.30	9.50	13.00	10.00	*6.00
F	4.60	5.30	5.30	8.60	8.00	11.80	10.30	11.00	11.90	11.00
G	3.00	4.00	6.50	6.25	7.25	7.50	8.50	8.00	7.00	*5.50
H	7.20	7.60	7.60	9.70	8.30	12.50	11.30	13.00	*	*
I	5.00	5.00	5.00	5.00	4.50	5.50	6.75	8.00	*7.50	6.00
J	7.25	8.00	11.50	11.50	12.00	12.00	12.00	12.25	12.25	*7.75
K	7.40	8.80	11.40	12.70	13.82	8.23	*	*	*	*
L	7.70	7.70	8.50	10.30	10.30	10.30	9.70	*8.80	0.50	2.00
M	3.00	3.50	5.00	5.25	5.25	7.00	7.00	10.00	10.00	*8.75
N	5.50	5.50	6.50	6.00	6.50	9.00	9.50	11.00	10.00	*
O	4.00	4.00	5.00	5.75	9.50	12.50	12.50	14.00	13.00	*10.00

*Overfired.

marked with the proper percentage, from which the imaginary base-line for each curve can easily be picked out. No two curves refer to the same base-line.

By this method of plotting, the shape or contour of a number of curves can be easily and rapidly compared, and the numerical value of each can be ascertained with a moment's attention.

Inasmuch as these clays have already been studied for color changes, and the temperature zones within which they are of commercial grade have been determined, it was thought useful to plot these zones on the shrinkage curve of each clay. Thus clay O is of commercial color between cones 02 and 3, and the line is doubled in thickness between these points, to indicate that this zone only is of direct use in the roofing tile industry.

Lastly, the angularity and inconsistent jogs of the curves are not to be construed literally at all. Clays probably do not shrink in this erratic fashion. Shrinkage is not a free factor—the structure of the clay mass, its shape, size, its position in the kiln, its cooling treatment and many little things all unite to make shrinkage data erratic, and only by obtaining large numbers of tests on one clay, and averaging them, could the true course of the shrinkage habit be accurately plotted.

Taking up the discussion of the clays, each in turn—

Clay O—This clay changes volume slowly up to cone 04, thence rapidly up to 14.00 per cent. at cone 3, bloating 4 per cent. in the next two cones. The commercial area falls in the zone of rapid shrinkage

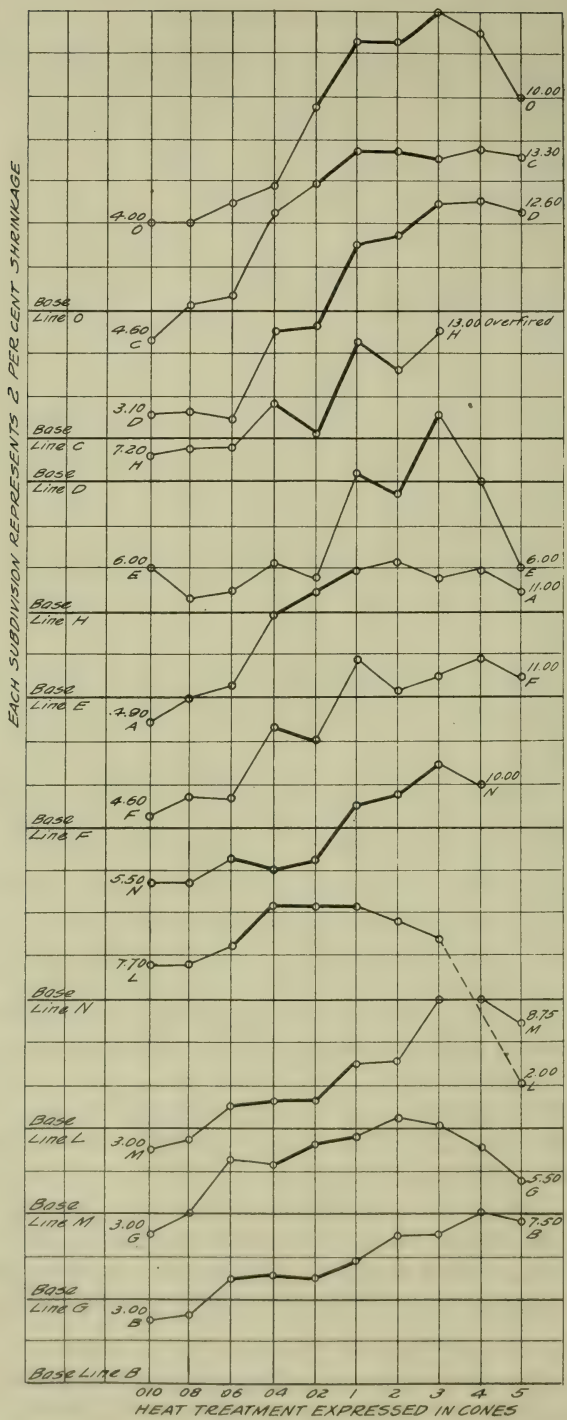


Fig. 31—Curves Showing Changes in Linear Shrinkage of the Standard Roofing Tile Clays at Various Stages of Heat Treatment.

and is immediately followed by bloating. It would seem to be difficult to so fire a kiln of this clay, as to secure even shrinkage and even color in all parts of the kiln and at the same time avoid the production of some overfired goods.

Clay C—This clay has a very much better habit. It shrinks rapidly and steadily from cone 010 to cone 02, but from cone 02 to cone 5 its volume is nearly constant. The total amount of shrinkage is high, 13.6 per cent., but this disadvantage is much more than offset by the long period of stability when shrinkage is once complete. The zone of commercial color also falls in the zone of stable volume. This clay should be of excellent properties for this purpose.

Clay D—This clay begins its volume change at cone 06, and becomes stable at cone 3, remaining so to cone 5, at least. The total amount of shrinkage, 13.20 per cent., is high. The zone of commercial colors falls in the period of rapid volume change and the difficulty of getting uniform size and uniform color would probably be considerable.

Clay H—The clay changes but little in volume till cone 04, when a moderate fire shrinkage of 5 per cent. (13 per cent. total) occurs. The clay bloats badly if fired above cone 3. The color zone from 04 to 2 coincides with the zone of most rapid shrinkage. This clay does not seem particularly fortunate in its combination of properties.

Clay E—This is a calcareous clay of buff color, requiring a slip clay covering to make it saleable. The clay does not change perceptibly in volume up till cone 02, but remains during this time very soft and not very durable to weather or wear. It can, however, be kept of constant volume over a whole kiln, and by slipping, of a constant color. It is possible, therefore, to use this material for roofing tiles with good results if the porous tiles can be disposed of. If, on the other hand, it is desired to vitrify the clay, the task is troublesome. There is no range at all at the top of the curve. Bloating and failure occur very quickly after cone 3 is reached, and prior to cone 3 the body is shrinking very rapidly. It would be impossible to produce hard, dense products from this clay in quantity, on account of the losses from either under- or overfiring.

Clay A—This clay is an unusually favorable one. The total shrinkage is 12 per cent., but its temperature range, after shrinkage is practically over, is 8 cones wide. The zone of good colors is 4 cones wide, and volume changes are largely over before the color is matured.

Clay F—The determinations are somewhat erratic, but the clay probably begins to shrink at cone 06, reaches maturity at about cone 1, remaining practically constant up to cone 5. This clay has a bad color and would have to be slipped, so that so far as can be seen a burning temperature of 01 to 3 would find the clay changing but little, and the color as good here as at any other period. Any place between cones 06 and 1 finds the vitrification process actively in progress.

9—G. B. 11—1,000.

Clay N—The contour of this curve seems exceptionally favorable, but the clay is one of the highly limy ones, and its slow and moderate changes are due to this fact. The body is soft and porous during the entire period, from cone 010 to cone 3, when it passes abruptly into vitrification and fusion. This clay would have to be slipped in any case, so that it could be used at the zone 06 to 01 with good results, if a porous body could be marketed.

Clay L—This clay has a drying shrinkage, but the fire shrinkage is very light and the rate of change very gentle up to cone 1. The preponderance of clay K in the mixture, with its very low point of maturity, causes the mixture as a whole to deteriorate rapidly at cone 1. From cones 04 to 2 the conditions are favorable. The clay would probably have to be slipped in any case, so that the best part of the curve should be selected as the finishing zone.

Clay M—This is a clay of exceptional properties. A good color, a very low shrinkage, a very gentle rate of change from 06 to 2, and no rapid failure from overburning imminent, make this one of the best yet considered.

Clay G—The same conditions here prevail. The clay ranges from 06 to cone 3 with gentle changes, and has a fairly wide color zone in the most stable part of the curve.

Clay B—Exceptionally favorable. Small shrinkage, slow changes, wide range in which the color is good, 06 to 1, and no rapid failure after the colors become too dark for roofing tile, make this clay an unusually favorable one for safe burning.

A summary of the above shows:

Classed as favorable—B, G, M, A, C among the red burning clays, and E, L and N among the porous, buff burning clays which would require slipping.

Classed as unfavorable—O, D, H, and F.

Fire Shrinkage.—By subtraction of the initial or drying shrinkage from the total shrinkage, we can learn the amount of change in size which is directly due to vitrification changes. This information is in some connections useful, but ordinarily the total shrinkage suffices. In the following table, (Number 28), the fire shrinkages have been calculated for the present series of trial pieces.

In examination of the fire shrinkage apart from the total shrinkage, it is undoubtedly easier to compare and contrast the vitrification changes, than when each observation is modified by the inclusion of the drying shrinkage. But it is not, in the present instance at least, possible to reach any new or different conclusions as to the relative safety or desirability of the clays, than those obtained from the study of the totals.

TABLE No. 28.

Showing Per Cents. of Fire Shrinkage on the Standard Roofing Tile Clays.

Designation of Clay.	Heat Treatment Expressed in Cones.									
	010	08	06	04	02	1	2	3	4	5
A	0.60[1]	0.50[1]	1.60	5.15	5.90	6.30	6.70	6.11	6.40	6.00
B	0.00	0.25	1.50	2.00	2.00	2.50	4.00	4.00	5.00	5.00
C	0.10	0.80	1.70	6.00	5.90	8.50	9.00	8.70	9.10	8.80
D	0.40[1]	0.30	0.10[1]	3.50	4.30	6.95	7.35	8.75	9.45	8.70
E	0.00	0.40[1]	0.10[1]	0.20	0.10	4.30	3.50	6.25	5.00	6.00
F	0.90[1]	0.20[1]	0.30	3.35	2.75	6.30	5.30	7.00	6.40	6.50
G	0.50	1.50	4.25	4.50	5.25	5.25	6.50	6.00	5.00	4.50
H	0.30[1]	0.10	0.10	1.70	0.80	5.00	3.80	5.50	[2]	[2]
I	0.50	0.50	0.50	0.50	0.00	1.25	2.75	3.75	3.75	2.25
J	1.25	1 75	4.25	5.50	5.50	6.00	5.50	5.85	5.85	0.50
K	2.59	3.89	6.49	7.79	8.69	3.10[3]	[3]	. . . .	. . . .	. . . .
L	1.00	2.20	3.00	4.30	4.80	4.80	4.40	3.50	5.00[1]	3.00[1]
M	0.30[1]	0.20[1]	1.30	1.55	1.55	3.30	3.30	6.00	5.50	5.15
N	0.00	0.00	0.00	0.50	0.50	2.50	3.75	5.50	6.00	[2]
O	0.00	0.00	1.00	1.87	5.50	6.50	7.00	8.00	8.00	4.50

[1]—Increase over original dry measure.
[2]—Melted.
[3]—Bloated.

WARPAGE.

The tendency exhibited by clay wares to warp or deform at some stage in their treatment between the time they leave the machine, or die, or mould, or hands which formed them, and the time when they come from the kiln a finished product, is well known to all clay workers. It is a defect peculiar to clay products in greater degree than almost any other kind of product. Glass wares, metal wares, cement wares etc., deform but little—if they are once formed true, they will remain true unless by the intervention of some accidental, exterior force. In these products, the finishing of the form is the last stage of the process —the iron or the glass or the cement fills its mould, hardens there, and generally remains true.

In clay wares, the forming is followed by two operations upon which the permanence of the ware depends—drying and burning. In both, the clay changes its volume materially, and in the latter, it changes its chemical condition from a mixture of uncombined and unrelated mineral particles, to a more or less uniform, homogeneous solution, surrounding such portion of the original grains as still wholly or partly retain their mineral identity.

Obviously, in these profound changes, every opportunity is offered to the clay to relieve itself of any strains which may remain from the process of forming or passage through moulds and dies under pressure.

Also, strains arising from improper balance of the parts of a piece of ware, thick portions vs. thin ones, etc., result in strains both in drying and vitrification, and if the clay approaches a viscous state in firing, these strains naturally tend to relieve themselves.

Lastly, clay wares of many sorts are brought in firing as near to the condition of a viscous fluid as the stability of the shape will in any wise permit, and often a little more than is safe. Clay wares in position in the kiln are usually set so that they carry more or less weight—frequently very heavy loads—and, under the influence of the incipient viscosity, they are deformed at temperatures where a single piece, sitting free, would remain true and sound. If a clay ware reaches a degree of viscosity when it is no longer able to hold up the load of its own weight, sitting free, without deformation, it is usually considered as fused, or in a state of viscous fusion. But in this case, all changes which take place must be such as a fluid would undergo in attempting to assume the horizontal—like a sagging or "wilting" of a stand of sewer pipes, etc.

Warpage is to be distinguished from fusion only as a matter of degree. It must proceed from the viscosity of the clay mass. But it may occur in bodies which have not nearly approached the condition of viscous fusion. Further, the change of shape may be the reverse of gravitational, and the ware may spring in any direction, up or down, out or in, under the influence of strains existing in it since forming. Third, these changes may take place with but little obvious progress of vitrification. Yet in the main, and on the whole, it must be believed that it is the *viscous condition of the clay, or some portion of it,* brought about by incipient fusion in burning, *which makes warpage possible.*

Roofing tiles are peculiarly susceptible to warpage. They are thin, of large area, and often stand up from the supporting surface in the form of arches. They are cheap and must be fired *en masse*—they cannot be accorded individual heat treatment in setting, for their price does not warrant it. Hence, every opportunity of structure and treatment is present in their manufacture and it is not strange that warping is a common and almost ubiquitous defect.

The measurement or systematic study of warpage has been neglected in previous reports on the clay industry. In a search of available ceramic literature, very little could be found that touched directly on this property of clay. In the past, the universal practice has been to consider warpage as a shrinkage trouble; that is, a clay with a high shrinkage would be expected to warp badly. In a general way, this may possibly be true, but such a theory leaves very much to explain in studying warpage.

By the term viscosity is meant the degree of fluidity of the clay, in flowing or bending while under heat. For instance, tar is said to

be a fluid of high viscosity, while water compared to tar is of low viscosity, and alcohol is of still much lower viscosity than water. In silicates, the viscosity of the slag of a charcoal iron furnace is of a high order, since it creeps out slowly, inch by inch, over the open hearth, and is being broken up and carted away as a glassy solid at the other end of the slag-stream, only a few feet from the point where it has issued from the furnace. A coke blast furnace, on the other hand, produces a slag of low viscosity, which flows like a fiery torrent through the cinder runways, but chills almost at once from a thin fluid to a solid. A few per cent. difference in the ratio of silica, alumina and lime produce these remarkable variations in viscosity.

In the same way, clays with a high degree of viscosity would be expected to resist warpage, while ones with a low viscosity, i. e., a thin fluid fusion, lend themselves very freely to this trouble. On the theory that chemical and mineralogical composition are instrumental in this defect, the following references were found bearing more or less directly on the situation:

Influence of Feldspar.—That complete vitrification is not necessary to the development of warpage has been shown by Day and Allen.[1]

The above writers in an attempt to study the viscosity of feldspars at their melting point prepared slivers of the feldspars about one by two by thirty millimeters. These slender trials were then spanned across small empty platinum crucibles, and placed side by side in the furnace. These exposed crystals were heated to 1,225° C. for three hours. When removed, they were completely amorphous (melted), but retained their position with hardly a trace of sagging. Other slivers were heated in some instances to 1,300° C. for a few moments, and while at this temperature a platinum rod was inserted through a hole in the top of the furnace, and allowed to rest as a load upon the middle of the crystal bridge. Under this load, the slivers gradually gave way. Slides cut from these trials showed no squeezing out of the melted portion between the crystal fragments on the side towards the center of curvature, or open cracks on the outer side. On the other hand, there was evidence of the bending of the crystals as well as of the vitreous portion.

They further say, with a degree of confidence, that the order of magnitude of the viscosity of the molten portion is the same as the rigidity of the crystal at these temperatures.

From the above, it has been shown that while the feldspars had completely fused or melted, their viscosity was so high that deformation did not take place until a load had been applied.

While Day and Allen have shown that pure crystals of feldspar are extremely viscous, the actions of these same feldspars in connec-

[1]Am. J. Sci., Vol. 169, page 93.

tion with a mineral mixture like ordinary clays might be very different. In the latter case, the feldspar might have an affinity for some portions of the mixture, and form fluid compounds that might possess a low degree of viscosity, which in turn might be imparted to the whole mass, causing warpage.

Again, it might be possible, under some conditions, for the glass, formed by the fusion of the feldspar, to drain to the lower parts of the mass, leaving the upper portion unfused and porous. The well known "liquation" of platinum-gold alloys, in which the gold drains to the lower portion of the mass, leaving a platinum skeleton above, is a case in point. The silicate skeleton thus remaining might possess rigidity enough to overcome the low viscosity of the fluid matrix in the lower sections, and thus prevent warpage. In this manner, it might be possible to have a considerable degree of vitrification in a clay unattended by warpage.

The action or influence of feldspar upon an ordinary clay is unquestionably a matter of condition, depending upon the size of the grains of feldspar and their relation to the other ingredients. Should the feldspar be present in relatively large grains, its influence would largely be that of resistance to warpage, while the same quantity of feldspar finely pulverized and intimately mixed throughout the mass could cause a rapid reduction in the degree of viscosity of the clay as a whole.

Influence of Mica—In the past, mica has in general been considered to act as a flux to clays, after the manner of feldspars; it has, however, been proved that its action upon clay will depend very largely upon the size of the grain.

Stull[1] has shown that mica when extremely fine-ground acts as a flux upon clay, but not to the same extent as feldspar. In large flakes, however, it may act directly opposite. It is not at all uncommon to find flakes of mica remaining unaffected in hard-fire biscuit ware, proving that in large grains mica does not act as a flux at cone 8. Thus, if distributed throughout a clay mass in relatively large pieces, it may have a strong action upon the viscosity of the clay by its slowness to react with the other ingredients. Mica taken alone requires about cone 13 to melt it, as shown by Rieke[2]. When present in ordinary clays or shales, burning at or near cone 1, it is therefore not likely that mica assists very greatly in softening the body, but is more apt to increase its degree of viscosity, as a sterile ingredient.

Influence of Alumina.—Purdy[3] says, "Alumina not only raises the actual period at which fusion is completed, but also causes the

[1]R. T. Stull, "The Fluxing Power of Mica in Ceramic Bodies." Trans. Am. Cer. Soc. Vol. IV., p. 255.

[2]Rieke, R.—"The Action of Calcium Mica on Kaolin." Sprechsaal, 1908, 577.

[3]Purdy R. C.—"Further Studies on White Bristol Glazes." Trans. Am. Cer. Soc. Vol. V., p. 136.

ware made from aluminous clays to soften and deform very slowly. The slower softening and deformation of ware made from aluminous clays has been attributed to viscosity of the mass caused by alumina."

The same writer[1] has shown that the addition of alumina as a constituent in a stone ware glaze, up to a proportion of alkali and alkaline earths to alumina of 2.5 to 1, not only rendered the glaze more fusible, but also less viscous.

Additions of alumina above this proportional amount, however, increased the refractoriness of the glaze, and its viscosity.

It is a well known fact that additions of alumina in slags and glasses above certain limits or proportions will increase their viscosity.

Frink[2] says that glass containing 0.6 per cent. or less of alumina will be found to be considerably less viscous than glass which contains from 3 to 4 per cent. of alumina. The latter glass, due to its greater viscosity, will be tenacious and more desirable to work, and will show a less tendency to retain the imperfections of the moulds.

Thus, the manner that alumina may act upon viscosity will depend upon its relative proportion to the other substances present.

Influence of Magnesia.—In a paper by Hottinger[3] it was pointed out that magnesite or dolomite added to a shale very greatly widened its vitrification range, as shown by the following table:

TABLE No. 29.

Hottinger's Experiment on the Influence of Magnesite upon the Fusibility of Clay.

No.	Mixture.	Absorption.			
		Cone 05	Cone 1	Cone 3	Cone 5
C 1	Shale 100, Whiting 25 ..	21.9	Melted ..	Melted ..	Melted.
C 2	Shale 100, Whiting 12.5	20.4	Vitrified..	Melted ..	Melted.
C 3	Shale 100, Magnesite 21.	32.8	7.3	Vitrified..	Shape retained.
C 4	Shale 100, Magnesite 10.5	28.4	0.32	Vitrified..	Slightly swelled
C 5	Shale 100, Dolomite 22..	22.4	11.5	Partially melted.	Melted.
C 6	Shale 100, Dolomite 11..	17.7	12.1	Blistered	Melted.
	Shale without additions.	12.0	0.78	Blistered	

[1]Purdy, R. C.—Illinois Geol. Survey, Bull. IX, p. 217.

[2]Frink, R. L.—"The Effect of Alumina on Glass." Trans. Am. Cer. Soc. Vol. XI, p. 99.

Hottinger, A. F.—"The Influence of Magnesia on Clay." Trans. Am. Cer. Soc., Vol. V, p. 130.

From the preceding tab'e it is evident that mixtures C3 and C4 are strongly viscous, though vitrified completely. At cone 5 they have retained their shape, while mixtures of the same shale with whiting melted completely at a lower temperature, and with dolomite the action was intermediate in severity. Hottinger further says, in reviewing the previous work of Mäckler[1] on the same subject, that clays carrying high magnesia can be made into wares of extreme length, with very thin walls, which may be very nearly vitrified, and still be kept perfectly straight and true. Also, the district in which Mäckler made his first observations on the effect of magnesia was a roofing tile district, and the tiles produced from the clays of one part of the district warped badly, while clays from the other part of the district did not. Mäckler found the magnesia content to be the only important difference in composition, and later verified by synthetic experiments the role of magnesia in reducing warpage.

It is believed that these results are due to the extreme viscosity of the magnesium silicate compounds, which allow a more complete vitrification without failure.

That many red-burning clays and shales in this country contain magnesia in various quantities, even up to several per cents., is a well known fact. Thus, it is quite possible that magnesia is playing a larger part in the prevention of warpage than is commonly supposed.

Influence of Lime.—The influence of lime upon the warpage of a clay will be dependent upon its size of grain and distribution. When present in lump or granular form, it is not probable that it assists warpage any more than any other particles, but when incorporated throughout the mass in large quantity and a finely divided state, it tends to keep the body porous and to delay shrinkage and vitrification and to hold the body free from warpage up to the point where combination begins. From thence, it causes the body to soften with extreme rapidity. Such warpage as occurs in this connection is palpably that of imperfect fusion.

In clays containing small amounts of lime (5 to 10 per cent.) finely divided and evenly distributed, its action is towards early fusion and rapid failure. The action is the same in quality, but the temperature at which it occurs depends on the quantity of lime, being low for low lime, or high for high lime.

Experimental Work on Warpage—With the foregoing general knowledge of the trade conditions as to warpage, and the theoretical discussions just quoted as to suggested relationships between mineral composition and warpage, some practical tests of the relative warpage of actual roofing tile clays was taken up. No records of any actual measurements or tests of warpage could be found, and therefore the method of inves-

[1]Mäckler, Dr. H. Influence of Magnesia on the Behavior of Clays, Tonindustrie-Zeitung, Vol. 26, II, p. 705.

tigation was necessarily entirely original and tentative. A large amount of the work which has been done in the testing of the standard roofing tile clays has been directed to the measurement of this property, so as to be able to pick out those clays which warp, or tend to warp, badly. Three separate experiments were made upon each clay in the series, excepting O and L, of which the supply of clay secured was insufficient.

First Experiment on Warpage.—It was thought that much could be told of the likelihood of the clay to warp by making thin flat tiles or quarries, and burning them upon flat surfaces, and noting the amount of "dishing," i. e., the curling up of the sides of the tiles, forming a shallow concave surface.

For this test, tiles one-half inch by four and one-fourth inches by four and one-fourth inches were made, by batting out blanks of approximately the correct thickness, then cutting them to a size that would just enter the die of a screw-tile press. The blanks were carefully pressed, especial attention being paid to getting them all as nearly of the same thickness as possible.

After pressing, the tiles were carefully placed upon selected straight boards, or pallets, where they were left until completely dry before handling, in order that no undue strains might be introduced. When these tiles were dry, they were set upon especially selected fifteen inch by twenty inch fire clay slabs, and placed in the chamber of a coke-fired down-draft kiln having a capacity equal to about 300 bricks. In order to obtain as much dishing as possible, it was thought best to place these trial pieces in the upper part of the chamber, where they would receive the direct action of the heat.

In order to learn the time at which warpage occurred, a series of four separate burns was carried out, finishing at cones 09, 07, 04 and 01, respectively. It was the intention to stay within the workable temperature limits of the clays, hence no burns were made above cone 01.

The time spent upon each of the four burns was about thirty hours. While more time would possibly have been better, it was firmly believed that the most severe test to which a badly warping clay can be put is a short, rapid firing, which does not give time for proper equalization of the strains.

After assembling the trials from the four burns, they were studied to note their amounts of dishing. Instead of being "dished," they were, with very few exceptions, "bowed"—that is, the center of each tile had raised or drawn up, while its sides or edges rested upon the fire clay slab which formed the floor.

In order to measure the amount of "bowing," a shallow, open-topped box a little larger than the tile was taken, and over the top from side to side a fine silk thread was stretched taut. A tile was placed in

the box, with the convex side up. Then, with a millimeter scale graduated to 0.25 mm., a direct measure was made from the thread to the center of the convex surface and then to the two edges directly under the thread, thus obtaining a difference in reading, dependent upon the amount of convexity.

In order to compare the amount of dishing or bowing in the different clays, all measurements were figured in per cents of the total distance from the silk thread to the box—that is, the measurement from the thread to the top of the tile was subtracted from the total depth from thread to the floor of the box. This amount was divided by the total depth, this quotient multiplied by 100, giving the figure in per cents of the total distance.

While it was assumed that the tiles were all of one thickness, it is true that there were slight differences due to the differences of shrinkage, but no allowance was made for this.

On tabulating these data, (Table 30) it was observed that clays which were known to warp badly in actual practice gave here different results under different heat treatment. For instance, clay G has at cone 07 bowed 1.56 per cent., at 04 it is straight, and at 01 it developed a dishing of 6.25 per cent. In other words, it would appear that at cone 04 the clay has so softened that it has straightened out, and yet at a higher heat it curled again in the opposite direction. In clays L, N, K, G, B, M and C there have developed both dishing and bowing of the trials. Just what conditions prevailed in the tiles or in the firing to produce such irregular results cannot be said.

There appears to be very little relation between shrinkage and warpage, as shown by clays A and E against clay G. The two clays A and E have a relatively high total shrinkage, and have remained straight, while clay G, having a rather low total shrinkage, has developed considerable warpage. Clay B, with a very low shrinkage, has warped to a considerable degree at the higher temperatures tested.

In a general way, it will be seen that those clays which warp badly in this test, such as J, K and L, warped badly in the succeeding tests, also. But this test did not seem to give a satisfactory expression to the tendency of clays to warp, and another test was devised to take its place.

Second Experiment on Warpage.—Much trouble results from a difference in the burning shrinkage of the two ends of auger-made Spanish tiles. The cause of the trouble is due largely to the method of setting the tiles in the kiln. As stated elsewhere in this report, auger-made Spanish tiles are set standing on end, in open fire-clay boxes or saggers. After burning, the end of the tile that was down is very often found to be larger, and its curvature more flattened out, than the end which was uppermost. The cause of this is the restriction of the shrinkage by friction against its supporting surface, while the upper end had perfect freedom to shrink or warp without restraint. It was thought worth

TABLE No. 30.

Showing Results of First Warpage Experiment on the Standard Roofing Tile Clays.

Temperature in Cones.	Designation of Clays.													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
09	0.00	0.00	1.04*	0.00	0.00	1.04	0.00	2.61	0.00	2.61	5.73	0.00	1.56	1.04
07	0.00	0.00	1.05	0.00	0.00	3.13	1.56	1.04	0.00	1.04	0.00	1.05*	0.00	0.00
04	0.00	1.04	4.69	0.52	0.00	0.00	0.00	0.00	1.04	1.04	1.03*	0.52*	0.00	0.52*
01	0.00	2.08*	1.57	1.04	0.00	2.61	6.25*	1.04	2.09	7.29	8.33	9.37	1.56*	3.13*

*Concave or "dished." Other determinations show amount of convexity.

while to make this industrial difficulty the basis of a test of the comparative warpage of different clays. A set of trial pieces was prepared, of such shape and thickness that it was thought that the clays likely to to give trouble in practice would be sure to develop it. These trial pieces were made in the form of half-round tiles, or semi-cylindrical troughs, three and one-fourth inches long, with an outside diameter of three inches and one-fourth of an inch thick. They were made by pressing the clay by hand in plaster molds, much care being taken to produce them free from flaws. In order to prevent their becoming distorted while drying, pallets were made, upon which cleats were nailed just far enough apart to allow the sides of the half-rounds to stand between them. They were thus prevented from spreading or settling down while plastic.

After thoroughly drying, the trial pieces were carefully measured at each end, one end being marked. The trials were then set in the kiln, each standing free from its neighbor on a smooth fire-clay slab.

Fig. 32—Showing Trial Pieces for First and Second Warpage Experiments, in place.

It was thought that the upper or free end would draw in, while the lower end, due to its friction on its support, would be prevented from doing so, and thus giving a measurement of warpage. The trials for this test were burned in the same manner, at cones 09, 07, 04 and 01.

After obtaining the trials from the four separate burns, they were again carefully measured at both ends. Then dividing the difference between the unburned and the burned measurements by the initial

width, and multiplying by 100, gives the per cent. of contraction in width. As will be seen in table No. 31, there is in most cases a marked difference between the per cent. of contraction of the lower and upper ends.

This experiment would, no doubt, have proved more successful if the trial pieces had been made much larger and longer, increasing the load upon the lower end, and thus making the resistance to warpage greater. The thickness of the walls of the trial pieces should also have been increased, to prevent their bulging out. In the majority of the

TABLE No. 31.

Showing Results of the Second Warpage Experiment on the Standard Roofing Tile Clays. The Difference in Contraction of the Free and Restrained Ends of Half-round Tiles.

Designation of Clay.	Cone 09			Cone 07			Average.
	Per cent. Contraction Upper End of Tile.	Per cent. Contraction Lower End of Tile.	Difference.	Per cent. Contraction Upper End of Tile.	Per cent. Contraction Lower End of Tile.	Difference.	
A	1.59	1.59	0.00	2.63	1.82	0.81	
B	0.68[1]	0.139[1]	0.541	0.83	0.27[1]	1.10	
C	0.972	0.110	0.862	3.01	2.31	0.70	
D	0.481	0.278	0.203	0.27[1]	0.69[1]	0.42[2]	
E	0.744	0.604	0.104	0.59	0.89	0.30[2]	
F	1.25	1.06	0.19	1.09	1.91	0.82[2]	
G	0.55	0.41	0.14	1.32	1.87	0.55[2]	
H	0.291	0.298	0.007[2]	2.36[1]	2.21	4.57	
I	0.41[1]	0.55	0.96	0.70[1]	0.27	0.97	
J	3.35	4.58	1.23[2]	1.54	1.12	0.42	
K	3.38	2.54	0.84	5.15	1.77	4.38	
L	2.59	1.45	1.14	4.57	2.34	2.23	
M	.....	.....	.....	0.82	0.13	0.69	
N	5.20[1]	5.28[1]	0.08[2]	3.43	3.83	0.40[2]	
	Cone 04			Cone 01			
A	8.13	6.57	1.56	9.41	4.48	4.93	1.82
B	2.06	1.51	0.55	3.90	3.01	0.89	0.512
C	16.32	12.06	4.26	9.27	9.33	0.06[2]	1.470
D	8.31	2.84	5.47	1.75	1.62	0.13	1.55
E	0.86	0.714	0.146	4.83	3.94	0.89	0.038
F	3.71	1.65	2.06	7.92	6.52	1.40	1.117
G	6.07	4.84	1.20	4.41	0.666	3.75	1.41
H	0.00	1.16[1]	1.16	3.91	3.24	0.67	1.60
I	1.25	1.67	0.42[2]	2.13	1.43	1.70	1.01
J	16.94	15.05	0.89	0.43	5.78	5.35[2]	1.97
K	1.30	2.32	1.02[2]	13.46	7.91	5.55	2.94
L	6.58	4.76	1.82	4.01	3.76	0.25	1.36
M	0.82	1.54	0.72[2]	5.79	0.41	5.38	2.26
N	1.16	0.57	0.59	0.54	0.24	0.30	0.34

[1] Expansion, instead of contraction.
[2] Per cent. that the bottoms have contracted in excess of the tops.

cases where a greater contraction of the lower end than the upper was shown, it was due to the sides bulging out and spreading the upper end, while the lower end was held by friction from doing so. Again, it is quite possible that the personal factor in pressing such thin sections has played an important part in causing irregularities.

In studying the results of the second warpage trials it will be seen from the column of averages in the table that clay K has shown the greatest degree of difference between the two ends of the trials, pointing out this clay as the one most likely to give trouble from warpage. The results of this test on clay K have been confirmed by both of the other warpage tests.

In a comparison of the fire shrinkage and warpage, it is very clear from the behavior of clays K and C in this method of testing, that there is no relation between the numerical values of the properties in different clays. Clay K has a fire shrinkage at cone 01 of about 9 per cent. and has shown a warpage of 2.94 per cent. Clay C at cone 01 shrinks in the neighborhood of 8 per cent. and only shows a warpage of 1.47 per cent., or just one-half that of K.

Clays C, D, G, H and I show very similar warpage in the above test, and these same clays have fallen quite closely together in the two other tests for warpage as well. Clays M and B give erratic results in this test. It is believed, in the light of the third warpage test, that the figures for these clays are not representative, and that B and M should be classed with clays like C and D, while B as here shown belongs with clays E and N, and M with K. The clays E and N show a very low degree of warpage, but their high lime content, their slow vitrification habit, their porosity until nearly ready to fuse, and the suddenness of their fusion when it once begins, all show that their behavior would not be like the vitrifying clays composing the rest of the series.

All things considered, the second method seems to have but little advantage over the first, and neither are satisfactory.

Third Experiment on Warpage.—The third experiment more nearly approaches a correct method for measuring the warpage tendency of clays than does either of the others tried, and it is believed than any other method known at the present time. It consists in supporting a long bar of clay on knife-edges in the kiln and measuring the amount and rate of sag developed in burning.

It is believed that Dr. E. Cramer, of Berlin, Germany, was the first to use this method in the study of clays. The Holdcroft thermoscope, a patented English pyrometric device, closely resembling the German Seger cones in composition, uses exactly the same principle in its test bars, which are laid horizontal on supports, and which betray fusion by sagging, instead of curling over as the triangular pyramids called "cones" do. It is not known, however, that this idea has

ever been used in this country prior to this investigation, or for this purpose.

The work as carried out consisted in passing the previously tempered clays through the Mueller auger machine and out through a flat shingle die, in a bar one-half inch thick by six inches wide. As the bar of clay issued, it was cut crosswise into thirteen-inch lengths, which in turn were cut lengthwise into strips one and one-fourth inches wide by thirteen inches long, after being placed upon a pallet. No handling of the small thin strips of clay after cutting was necessary. Much care was taken to select perfectly straight pallets upon which to dry these bars. In order to avoid drying strains as much as possible, the trial bars were all carefully dried in an open room until they were white-hard, after which they were placed in a drying-oven while still on the pallets. When dry, they were taken to the coke-fired down-draft kiln mentioned before, and placed for firing. It is in the method of setting that the real test of the clay consists.

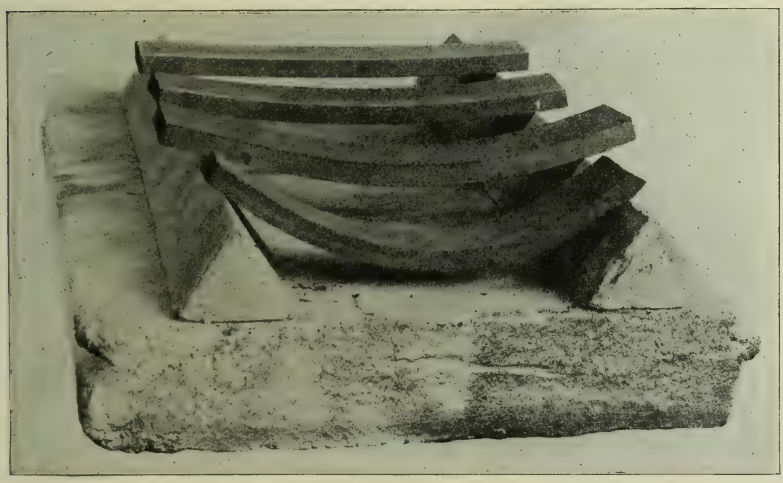


Fig. 33—Method of Setting Warpage Trials on Supports.

From the above cut it will be seen that the trial bars were set upon fire-clay knife-edges (previously burned) placed 10 inches apart, center to center. The trial bars, which had been thirteen inches long when first cut, were for the most part about twelve inches long at the time of setting. Hence, with the knife-edges ten inches apart, there was an overhang of about one inch at each end for every bar. Two trial bars of each clay were set for each burn. While purposely not placed side by side, the two trial bars gave closely concordant results in every instance. In the four burns made, at cones 09, 07, 04 and 01, res-

pectively, it was the intention not to overfire any of the clays and keep within commercial temperature ranges for all of the different clays.

These test bars, one-half inch thick by one and one-fourth inches wide by ten inches long between supports and twelve inches, more

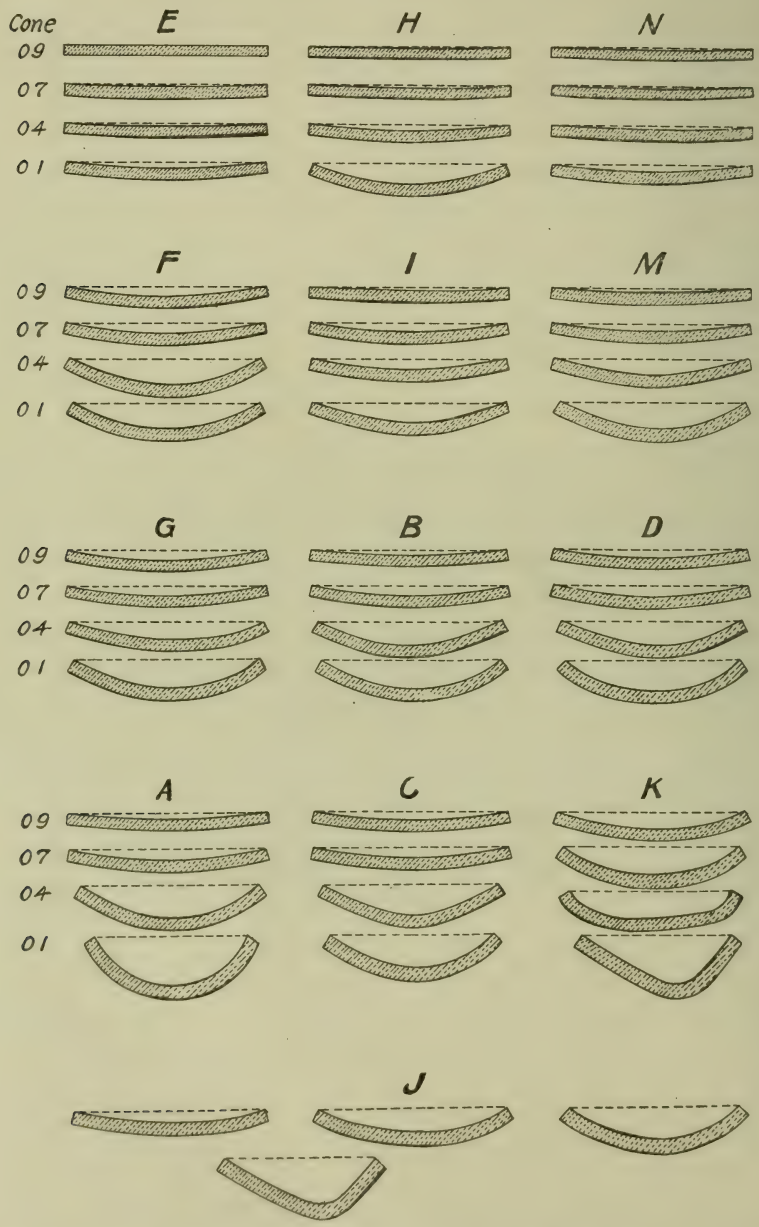


Fig. 34—Drawing Showing Sagging or Warping of Clay Bars at Different Temperatures.

or less, over all, naturally tended, on softening from the heat, to sag down in a more or less perfect arc of a circle, of which their original position formed the chord. The idea of the experiment was that the amount of the sag would afford a numerical index of the warping tendency.

In measuring the trial bars, it was assumed that they went into the kiln perfectly straight, i. e., with 0 per cent. warpage. The degree of sagging found after burning was measured by taking a thin flat rubber band and stretching it tightly from end to end of the tile across the intervening space like the string to an archer's bow, as shown by the dotted lines in Figure 34. Then by means of calipers graduated to the second decimal place, the distance from the under side of the taut band to the upper surface of the tile at the point of greatest deflection was taken, thus giving a direct measure and comparison of the warpage in the different clays.

After taking the above measurements, a two-inch piece was carefully broken from one end of each trial bar, and the porosity was determined with great care by the methods given in that connection.

The tables to follow have been prepared by taking the average of the two results for each clay for each burn, for the degree of warpage and for the per cent. porosity. The linear shrinkage figures were not available at cones 09, 07 and 01, and were interpolated from the table given under the head of "Fire Shrinkage." For cone 04 the observations required no interpolation.

In the above cut, the trial pieces are represented in their different degrees of warpage from a straight line at the four heat treatments, cones 09, 07, 04 and 01, respectively.

Clays E and N have deformed the least and at a slow rate. Clays K and J developed a very high warpage and at a rapid rate, i. e., the increase from cone to cone was decided. Clay A shows a warpage equal to J or K, but there has not been a decided failure of this clay as in clays J and K. It will be noted that they have sagged in irregular curves, while A has sagged in a very regular manner. Clay K was observed to deform badly by the time that the kiln had reached a dull-red heat, indicating very early changes under fire. The discrepancies of clay K in this and other tests before recorded, compared to the other clays tested, are probably due to the fact of its very early vitrification. Its curves of porosity, shrinkage and specific gravity are not different from the other curves in kind or contour, but the latter half of its vitrification period falls in the same temperature zone that witnesses the first half of the vitrification in the other clays. The result is that it seems all out of joint with the others. Without doubt, its full curves would be more normal in contour if our observation had begun at 750° C. instead of 950° C. (cone 010).

10—G. B. 11—1,000.

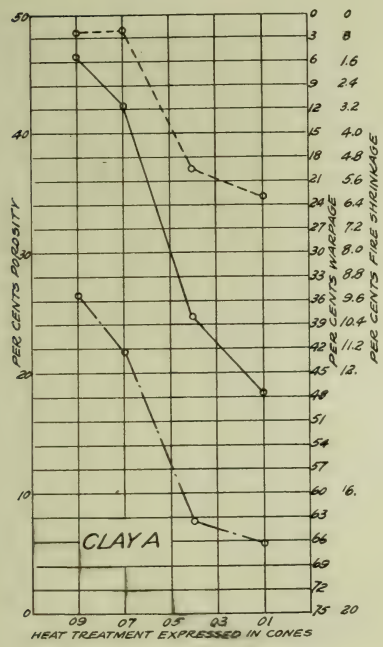
In the following tables are given the warpage as determined by this method. In addition, the fire shrinkage and porosity are given to facilitate comparisons.

TABLE No. 32.

Shosing Results of Third Warpage Test on the Standard Roofing Tile Clays with Results of Fire Shrinkage and Porosity Tests Added for Comparison.

Designation of Clay.	Temperature of Different Burns.					
	Cone 09			Cone 07		
	Per cent. Fire Shrinkage.	Per cent. Porosity.	Measure of Warpage.	Per cent. Fire Shrinkage.	Per cent. Porosity.	Measure of Warpage.
A	0.55[1]	26.49	5.27	0.55	21.71	11.80
B	0.12	26.24	5.57	0.87	19.26	12.55
C	0.45	32.72	5.95	1.25	28.44	10.92
D	0.05[1]	31.79	7.47	0.10	32.20	10.87
E	0.20[1]	39.54	0.00	0.30[1]	29.01	1.80
F	0.55[1]	31.05	8.10	0.05	30.11	11.22
G	1.00	25.28	8.50	2.87	23.83	11.12
H	0.20[1]	31.03	1.87	0.10	30.35	3.02
I	0.50	30.07	5.87	0.50	29.90	12.00
J	1.50	16.81	8.40	3.00	10.56	20.10
K	3.24	16.27	17.75	5.19	10.19	37.95
M	0.25[1]	30.96	6.10	0.55	28.03	10.15
N	0.00	36.32	1.32	0.00	36.13	1.62
	CONE 04			CONE 01		
A	5.15	7.57	38.02	6.10	5.75	47.15
B	2.00	11.81	29.50	2.25	11.74	42.00
C	6.00	11.86	36.75	7.20	8.81	47.15
D	3.50	28.74	21.82	5.62	23.01	41.30
E	0.20	38.34	2.47	2.20	34.88	8.60
F	3.35	22.42	24.95	4.52	18.91	41.55
G	4.50	12.75	32.15	5.25	10.70	41.55
H	1.70	29.20	8.27	2.90	26.02	24.80
I	0.50	31.29	15.02	0.62	25.13	25.40
J	5.50	2.99	35.50	5.75	2.82	61.15
K	7.79	6.65	37.30	5.89	2.78	62.00
M	1.55	25.73	19.25	2.42	22.26	40.50
N	0.50	37.91	4.55	1.50	37.57	5.75

These results have been plotted in the following curve sheets (pages 675-678). For convenience in observing, the warpage and fire shrinkage are made to read *down the page*, while the porosity *reads up*. By this expedient, all the curves are made to traverse the paper in the same direction. Also, the scale selected for each kind of data is different, and is chosen to make the curves change elevation at about the same rate *in the average case*. If one property changes faster than another, the curves immediately diverge.



In each of the following seven diagrams, the upper curve, platted in dotted lines, represents the fire-shrinkage. The middle curve, in solid lines, is the warpage data, and the lower curve, platted in broken lines, represents the porosity.

Fig. 35—Warpage-Porosity-Shrinkage Comparison for Clay A.

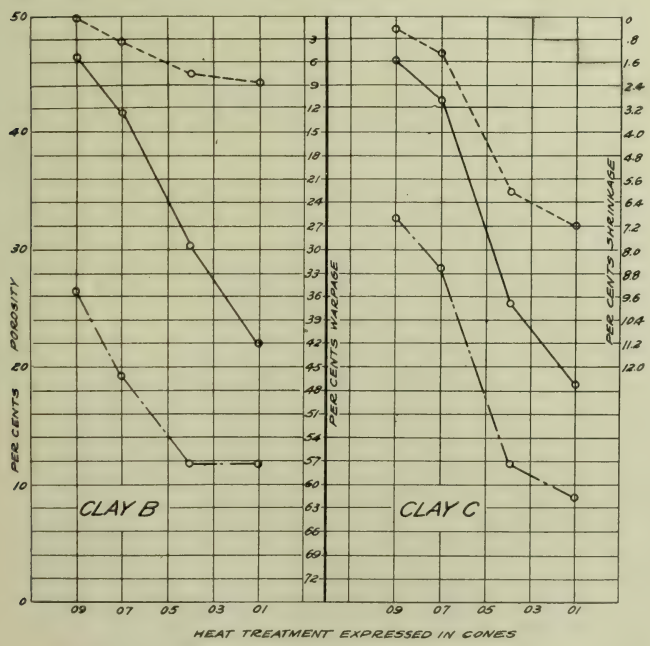


Fig. 36—Warpage-Porosity-Shrinkage Comparison for Clays B and C.

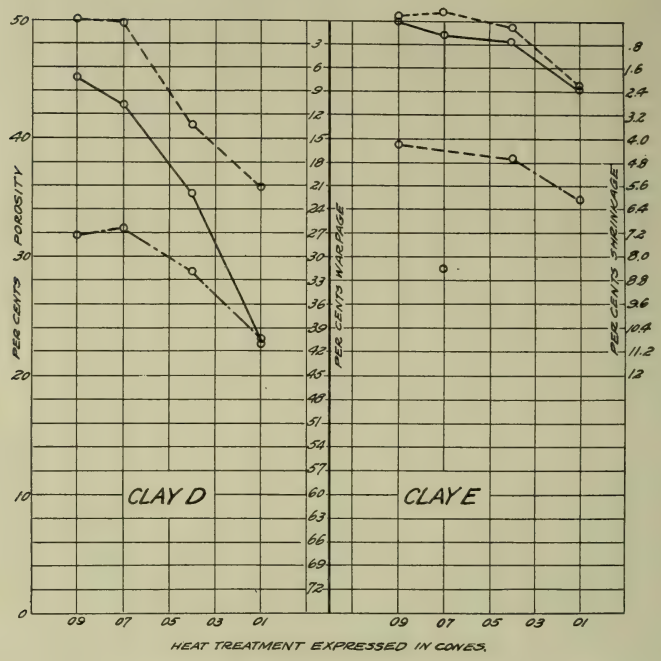


Fig 37—Warpage-Porosity-Shrinkage Comparison for Clays D and E.

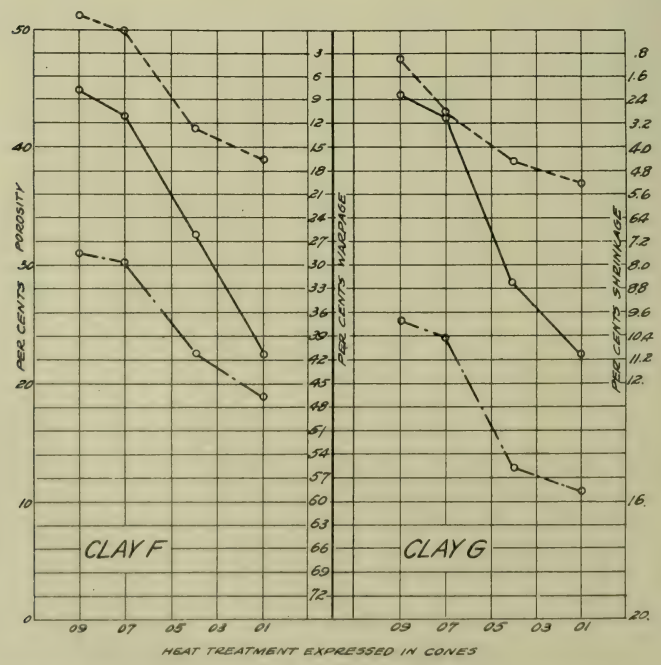


Fig. 38—Warpage-Porosity-Shrinkage Comparison for Clays F and G

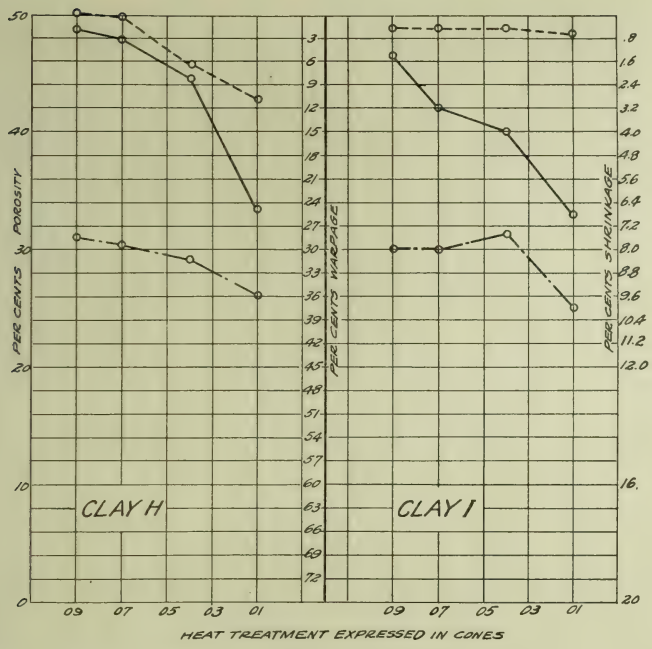


Fig. 39—Warpage-Porosity-Shrinkage Comparison for Clays H and I.

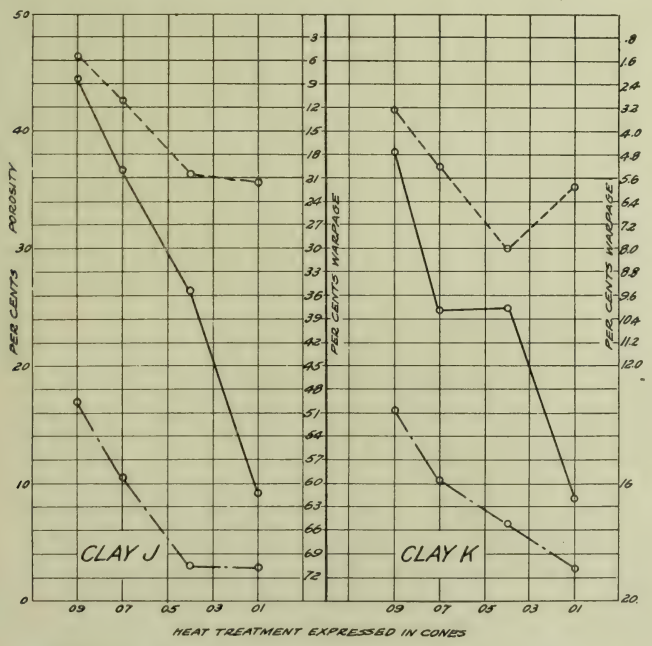


Fig. 40—Warpage-Porosity-Shrinkage Comparison for Clay J and K.

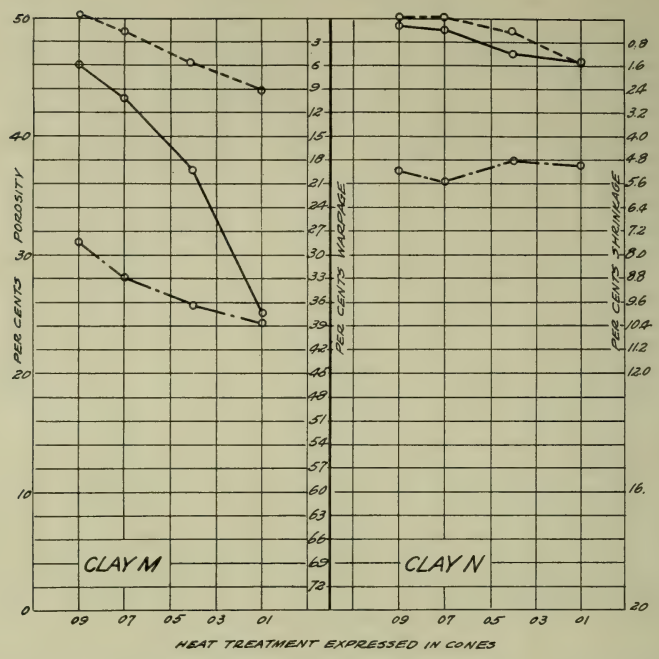


Fig. 41—Warpage-Porosity-Shrinkage Comparison for Clays M and N.

A careful study of these curves reveals the close relation which exists between the changes of volume and the changes of form. This is as has been assumed and expected, but up till the present no proof had been submitted, so far as is known.

There are, it is true, some puzzling inconsistencies in the data. These inconsistencies largely come, no doubt, from the fact that we are dealing with a very small number of trial pieces, and, as is well known, shrinkage data are notoriously erratic and can only be accepted as of much weight when they are the mean of a large number of determinations. The wonder is, therefore, not that there are inconsistencies, but that so much consistency can be gotten out of such a limited amount of material.

The three kinds of curves in clays A, C, E, G and N show a marked concurrence in direction and rate of change. No one, after looking at them, can fail to be struck with this fact. Clays A, C and G are all clays which shrink rather highly, decrease in porosity rather sharply, and warp rather evenly, but in considerable amount. Clays E and N are calcareous clays, which do not enter their active vitrification process in the temperature zone studied, and therefore neither warp nor shrink nor grow dense. They prove nothing, either pro or con, in this discussion.

In the clays D, F, H, J, K and M, we find again a marked concurrence between the rates of fire shrinkage, porosity extinction, and warp-

age, in the earlier portion of the temperature zone studied. Between cones 09, 07 and 04, the concurrence in direction and rate of change is marked. But between cones 04 and 01, the warpage consistently changes faster than the other properties do.

This might be construed as weakening the contention that warpage is a function of the vitrification process, and controlled by the same actions that control shrinkage and porosity, but in fact it strongly verifies and supports it. If we consider warpage as being the result of incipient fusion of the clay—the development of a viscous taffy-like material in the clay body, not sufficient in amount to cause the clay to actually liquify and lose its shape at first, but growing gradually in amount and fluidity as the temperature rises, until in the end it does cause the resistant frame-work of the clay to slump and the clay to fuse—then the increase of warpage more rapidly than the parallel changes in either shrinkage or porosity is the normal thing and should be expected.

We know that, as the porosity of an ordinary clay is extinguished, the rate of change becomes less and less with each increase of temperature. The progress goes on rapidly when the porosity is high, but gets slower and slower as it approaches the maximum density. Similarly with fire shrinkage. The maximum, in good clays at least, is reached by a series of slow approximations, followed by slow bloating, and the volume curve runs nearly horizontal for a time. But, while the last of the shrinkage and porosity are gradually taking place, the viscosity or incipient fusion is all the time gaining in force and power. Naturally, as the temperature rises to more and more critical points, do the warpage and deformation increase. It would be seen to increase still faster in proportion, if the temperature zone studied in this work had covered a still higher range. Curves D, F, H, J, K and M, therefore, represent the same thing as curves A, C, and G, except that they have gone a little further toward fusion, and the deformation between 04 and 01 has made more headway in the former than in the latter three. This is especially clearly distinguishable in clay J. Here we have the most complete extinction of porosity, with high fire shrinkage, that we have in the available data, and with it we get the highest deformation, and *the most marked increase in rate of warpage when the other properties have ceased to change.* In K, bloating has begun at cone 01, and this destroys the symmetry of the curves, though it would explain the high warpage.

In two of the thirteen clays examined, viz., B and I, we find the situation less easily read. B is remarkable only in its very low shrinkage. Its porosity curve and its warpage behavior are strictly concordant with most of the other samples tested. But how a clay can show such evident signs of viscosity with so little fire shrinkage is not understood.

In clay I, the curves indicate that the vitrification process was quiescent up to cone 04, neither fire shrinkage nor reduction of the porosity occurring. During this time a moderate or small warpage took place. At cone 04, porosity suddenly decreased, concurrent with warpage, but the fire shrinkage was still not affected. It is probable that a study of these clays over a wider temperature zone would assist in understanding their behavior.

From the foregoing, we may present the following general deductions:

First—Change of shape in the burning of a clay ware is a function of the vitrification process, and results from the formation of a viscous silicate matrix, while the principal part or skeleton of the clay is still solid.

Second—The changes of shape which occur early in the burn, while the clay ware still retains its general shape and usefulness, and those late changes from overfire which destroy the shape for commercial uses, are stages of one and the same process.

Third—Changes of shape are found to begin at temperatures far lower than was expected—a low red heat in one instance. In general, these changes are insignificant below cone 010.

Fourth—The rate of change of shape in normal clays is closely parallel to the rate of the other vitrification changes (shrinkage, porosity etc.) for a time. In most of the clays tested, this parallel lasted to cone 04 and in several to cone 01. But as the rate of shrinkage and porosity changes decreases on approaching completion, the rate of change of shape increases, so the curves do not remain concurrent at higher temperatures.

Fifth—The tendency to warpage and the absolute amount or numerical value of the warpage of a clay at any given temperature are inherent properties of the material, and do not admit of prophecy: i.e., knowledge of the behavior of one clay does not justify us in assuming what the next clay will do. Warpage stands on the same plane in this respect as the other properties of a clay. Nor can warpage be correlated at all closely in numerical amounts with the shrinkage, porosity, or other properties of the clay. For instance, two clays of equal warpage may or may not agree closely in shrinkage or porosity. Likewise, clays having the same shrinkage or porosity may or may not have similar warpage. Also, while high shrinkage and low porosity incline us to expect high warpage, it does not always follow—the relation is only a general one.

Sixth. In studying warpage of clays for commercial applications, trial pieces covering the entire temperature range from cone 010 or below up to the point of complete maturity or slight overfire should be secured, in order to determine the critical point where the deformation begins to take place at a faster rate than the concurrent changes in

shrinkage and porosity. This point indicates where the warpage may be expected to become severe.

Seventh. In estimating the value of clays for roofing tile purposes, or for making any thin-walled wares, the determination of the warpage tendency is a practical test, second in importance only to color and vitrification range.

SUMMARY.

In deciding on the clay to be used in a new enterprise, where all the data have been obtained that can be obtained as to its properties, a decision must be reached as to whether to accept or reject it. Enough has been shown in the foregoing series of tests to show that very rarely is any clay tested of which the properties are all favorable. Some defect is almost certain to be present. The question is where to draw the line between defects which are fatal and those which can be overlooked in consideration of the counterbalancing good properties.

In Table 33 (pages 682-693) the net results of the preceding tests have been reduced to their simplest expression and a decision characterizing the clay as a whole has been reached. This may be of use as an example for others attempting a similar judgment on similar data.

TABLE No. 33.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
A	Water required for Plasticity: Moderate, 18%.	Oxidation.	Fairly rapid.	Favorable.	A good material. High warpage is its most serious fault.
		Color.	Moderate. Commercial between cones 04-1.	Color quality is good.	
		Hardness.	Changes rapidly between cones 06-04.	Steel hard or harder.	
	Shrinkage in Drying: Moderate, 5.50%.	Porosity.	Extinguishes very regularly at 3.05 per cone.	Moderate 12 to 5%.	
		Specific Gravity.	Indicates good structure up to cone 3.	Favorable.	
	Strength in Dried Condition: Moderate, 6.33 lbs.	Shrinkage.	Unusually smooth and regular.	Moderate to high, 10% to 12%.	
		Warpage.	Rapid, but regular rate.	High. 38% to 47%.	
		Overfire.	Stands several cones with no damage except color.		

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
B	Water required for Plasticity: Low. Shrinkage in Drying: Low. Strength in Dried Condition: Moderate, 6.41 lbs.	Oxidation.	Fairly rapid.	Favorable.	An excellent material with an unusually favorable combination of properties.
		Color.	Slow, with commercial colors between cones 06-1.	Color quality is good.	
		Hardness.	Changes very slowly and steadily.	Hard enough, but softer than steel.	
		Porosity.	Extinguishes very slowly. Rate 2.26% per cone.	Rather high. 17% to 7%.	
		Specific Gravity.	Indicates good structure up to cone 4.	Favorable.	
		Shrinkage.	Exceedingly slow, and gradual in rate of change.	Very low. 5 to 5.75% (total.)	
		Warpage.	Regular in rate.	Average in amount. 29% to 42%.	
		Overfire.	Stands a lot of heat without harm, except to color.	Favorable.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
C	Water required for Plasticity: High, 22%.	Oxidation.	Quite slow.	Unfavorable, but not severely so.	A fair material, only. High warpage, high shrinkage, and quick vitrification make it a little difficult to handle.
		Color.	Moderate, but requires higher temperature than usual to get good shades. 02-3.	Color quality is good.	
		Hardness.	Changes rather abruptly between 04-02.	Steel hard or harder.	
	Shrinkage in Drying: Below average, 4.5%.	Porosity.	Extinguishes rapidly berween 06-04. Moderate rate thereafter. Rate per cone 4.17%.	Moderate, 14% to 4%	
		Specific Gravity.	Indicates good structure up to cone 3.	Favorable.	
	Strength in Dried Condition: Moderate, 5.95 lbs.	Shrinkage.	Rapid between 06-2. Very steady thereafter. Almost constant during period of useful colors.	High. 12% to 13.6%.	
		Warpage.	Regular in rate.	Rather high in amount. 36-48%.	
		Overfire.	A reasonable range available.	Favorable.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
D	Water required for Plasticity: Rather high, 20%.	Oxidation.	Exceedingly favorable.		A rather mediocre material. Properties are changing rapidly during the period of good colors, and overfire is easily reached. Raw properties not very good.
		Color.	Regular. Serviceable from 04-3.	Color quality is fair.	
		Hardness.	Changes are regular, reaching maximum at cone 1.	Hard enough. Harder than steel at finish.	
		Porosity.	Extinguishes rapidly 06-02. Moderate rate thereafter. Rate per cone 3.17%.	Moderate 13%–3%.	
	Shrinkage in Drying: Quite low, 3.5%.	Specific Gravity.	Gentle changes. Best at cone 02. No point of marked failure.	Favorable.	
		Shrinkage.	Steady from 06-3. Volume changing during entire period of good colors.	Varies from 7% to 13%.	
	Strength in Dried Condition: Low, 4.17 lbs.	Warpage.	Steady in rate.	Average in amount 33%–42%.	
		Overfire.	Not a large margin available.		

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
E	Water required for Plasticity: Moderate, 19%.	Oxidation.	Very slow and difficult.	Unfavorable.	A good material for porous tiles, by working below cone 02 and slipping the product. Entirely unfit for any other kind of tile.
		Color.	Colors are unstable over whole burn.	Cannot be used without slipping.	
		Hardness.	Slow and gradual changes to cone 02.	Soft below cone 1. Hard above that.	
	Shrinkage in Drying: High, 6%.	Porosity.	Extinguishes with great rapidity from 02-3. Rate per cone 9.55%.	Unfavorable for hard tiles. Good if worked below 02.	
		Specific Gravity.	Fails rapidly from cone 04.	Unfavorable.	
	Strength in Dried Condition: Good, 7.53 lbs.	Shrinkage.	Begins at cone 02. Changes exceedingly rapid.	Unfavorable for hard tiles. Good if worked below cone 02.	
		Warpage.	Does not begin actively till cone 1 or above.	Very slight up to cone 01.	
		Overfire.	No margin at all above 02.	Unfavorable to last degree.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
F	Water required for Plasticity: Rather high, 20.65%.	Oxidation.	Rapid.	Favorable.	A mediocre material. Color is against it, and its good properties are not sufficiently marked to overbalance the color handicap.
		Color.	Rapid and unreliable. Best is only from cone 04-02.	Quality poor at all times.	
		Hardness.	Changes from soft to hard abruptly at 02.	Inferior.	
	Shrinkage in Drying: Above the Average, 5.25%.	Porosity.	Moderately rapid from 06-3.	High. 24%.	
		Specific Gravity.	Failure of body begins at cone 2.	Favorable.	
		Shrinkage.	Changes between 06-1 are moderate. Very slight thereafter.	Low. 8%.	
	Strength in Dried Condition: Moderate, 5 lbs.	Warpage.	Regular in rate.	Average in amount. 27%-42%.	
		Overfire.	Range ample for all purposes.	Favorable.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
G	Water required for Plasticity: Very low, indeed, 13.8%.	Oxidation.	Moderately rapid.	Satisfactory.	A good material. Worst fault is its warpage, which is about average.
		Color.	Moderate. Best Zone 04-1.	Quality of color, good.	
		Hardness.	Changes rapidly at cone 02.	Steel hard or near it.	
		Porosity.	Changes are very gradual. Rate per cone is 1.92%.	Rather high. 16%-10%.	
	Shrinkage in Drying: Very low, 20%.	Specific Gravity.	Rapid fall at cone 4.	Favorable.	
		Shrinkage.	Changes are gentle and uniform.	Low. 6%-8%.	
	Strength in Dried Condition: Very weak, 2.76 lbs.	Warpage.	Uniform and steady rate.	Average in amount 33%-42%.	
		Overfire.	Sufficient range.	Favorable.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
H	Water required for Plasticity: Quite high, 21%.	Oxidation.	Very slow.	Unfavorable.	A mediocre material if not actually undesirable. Properties changing rapidly during available color zone, and easily overfired. Low warpage is its best asset.
		Color.	Steady and gradual. Best 04 to 2.	Quality of color only fair.	
		Hardness.	Changes abruptly at cone 02.	Variable from soft to harder than steel.	
	Shrinkage in Drying: Very high, 7.25%.	Porosity.	Rapid changes between 02-3. Rate per cone 5.93%.	High. 26%-10%.	
		Specific Gravity.	Fails rapidly after cone 02.	Unfavorable.	
	Strength in Dried Condition: Very high, 11.5 lbs.	Shrinkage.	Moderate between 04-2. Bloats easily.	Varies from 7%-13%.	
		Warpage.	Slow to cone 04. Rapid thereafter.	Low, 24% or less.	
		Overfire.	Narrow range.	Unsatisfactory.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
L	Water required for Plasticity: Moderate, 17.21%.	Oxidation.	Moderately rapid.	Satisfactory.	If slipped and worked as a porous product, the mixture is not undesirable except on account of its easily exceeded overfire limits, and its warpage. The latter is known from the high warpage of its three ingredients.
		Color.	Changes between 06 and 1 are slow.	Quality is poor at all temperatures.	
		Hardness.	Changes slowly.	Steel hard or just below.	
	Shrinkage in Drying: High, 6%.	Porosity.	Changes very gradual. Rate per cone 1.48%.	High. 22%-16%.	
		Specific Gravity.	Body begins to fail rapidly at 02.	Not favorable.	
	Strength in Dried Condition: Not determined.	Shrinkage.	Changes steady and small.	Moderate 8%-10%.	
		Warpage.	Not measured.	Cannot be favorable.	
		Overfire.	Very narrow range. Easily spoiled.	Unfavorable.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
M	Water required for Plasticity: Low, 15.86%.	Oxidation.	Moderately rapid.	Satisfactory.	A desirable material. Will make a rather porous tile of moderate warpage.
		Color.	Changes slowly between 06-1.	Quality good.	
		Hardness.	Changes rapidly at cone 02-1.	Hard enough. Below steel.	
	Shrinkage in Drying: Low, 3.5%.	Porosity.	Changes rapidly between 02-3. Rate per cone 6.02.	High. 28%-22%.	
		Specific Gravity.	Begins to fail slowly at cone 1.	Favorable.	
	Strength in Dried Condition: Below Average, 4.79 lbs.	Shrinkage.	Changes slow and small.	Low. 5%-7%.	
		Warpage.	Regular.	Below average in amount, 21%-39%.	
		Overfire.	No overburning for several cones	Favorable.	

TABLE No. 33—Continued.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
N	Water required for Plasticity: Rather low, 16.13%.	Oxidation.	Very slow.	Unsatisfactory.	If slipped and worked below cone 02, the properties of this clay are favorable for a porous tile. Absolutely unfit for any other.
		Color.	Changes very slow between 06-3.	Buff. Useless without slipping.	
		Hardness.	Changes vey slow.	Reaches steel hardness at 2.	
	Shrinkage in Drying: Moderate, 5%.	Porosity.	Changes very rapid between 02-3. Rate per cone 7.68%.	Very irregular, mostly high, 38%-6%.	
		Specific Gravity.	Begins to fail at 02 rapidly.	Not favorable.	
		Shrinkage.	Slow and gradual.	Low. 6%-10%.	
	Strength in Dried Condition: High, 9.05 lbs.	Warpage.	Very slight. Does not really begin till after 01.	Very low. 3%-6%.	
		Overfire.	No range at all, above 02.	Very unfavorable.	

TABLE No. 33—Concluded.

Summary of Tests on the Standard Roofing Tile Clays.

Designation of Sample.	Properties in the Raw State.	Behavior in Burning.		Standing of the Burnt Clay Within the Useful Color Range. Comparative Amounts or Effects.	Final Judgment.
		Properties of the Burnt Clay.	Rate of Change in Burning.		
O	Water required for Plasticity: Moderate, 18.74%.	Oxidation.	Moderately rapid.	Satisfactory.	A fair mater 1 only. Its porosity and shrinkage are both rather high, and its tendency to suffer from overfire is against it.
		Color.	Changes slowly 02-2.	Quality good.	
		Hardness.	Gentle and regular.	Steel hard.	
	Shrinkage in Drying: A little high, 5.50%.	Porosity.	Changes steady and not rapid. Rate per cone 3.36%.	Rather high, 20%-12%.	
		Specific Gravity.	Remarkably uniform. No failure at cone 5.	Very favorable.	
		Shrinkage.	Rapid from cone 04 to 1.	Moderate to high. 10%-14%.	
	Strength in Dried Condition: Not determined.	Warpage.	Not determined.		
		Overfire	Very little margin, a serious defect.	Unfavorable.	

CHAPTER IV.

THE PREPARATION OF ROOFING TILE CLAYS.

The processes to be considered in this chapter include all that deal with the winning of the clay, its transportation to the plant, its grinding, the production and increase of plasticity, its aging and its chemical treatment to avoid efflorescence.

In discussing these topics it has not been the intention to write a text book on all known methods of clay preparation, which would carry the book much beyond the proper limits, but to state somewhat fully how the roofing tile manufacturers are now actually solving their several problems, in the belief that a discussion of these facts may be of more use to roofing tile makers, present and prospective, than the more general treatment.

VARIETIES OF CLAYS USED.

The discussions of the preceding chapter on the clays used in roofing tile manufacture in this country have made clear their physical and chemical properties, and their origin, or geological occurrence, has been made known. In connection with the preparation of clays, it is again desirable to consider their varieties.

If the occurrence of the clays now actually in use in American roofing tile plants be tabulated, we will find as follows:

(1) Glacial clays, containing a considerable quantity of stone and lime	1 plant
(2) Alluvial or river flood-plain and lake-bottom clays, containing sandy streaks, but practically no stones or coarse impurities	3 plants
(3) Shale beds, accessible for superficial workings	9 plants
(4) Shale beds, under heavy cover, and requiring mining operations	1 plant
	14 plants

So far as winning is concerned the first two groups may be lumped together, as the modes of operation are in general the same. The superficial shale beds make a group by themselves, differing from the first two chiefly in the difference in hardness of the clay and the use of explosives to loosen it. A third mode of winning is represented in the single case of mining an underground vein.

WINNING ROOFING TILE CLAYS.

By winning is meant the operation or work performed in loosening a mineral from its natural bed and loading it ready for removal to its next destination. In many places the transportation and delivery of the material to its next destination are considered as a part of the definition of winning, but it seems better in the interest of clearness to keep these matters separated.

The methods employed are many, depending upon the nature of the material, its position with regard to the surface, its hardness, the quantity required, etc., etc. They may be roughly classified, so far as the present purpose is concerned, as open pits, quarries and mines.

OPEN PIT WORKINGS.

As a general thing, open pit workings are confined to soft clays, such as the glacial and alluvial types, which do not require blasting to loosen them, and which have not the necessary hardness and rocky structure to make either mining or quarrying possible.

Open pit workings take on very different proportions and characters in different parts of the world, according to the peculiarities of the clay beds, the customs of the country, the kind of labor, the climatic conditions, etc. In rare cases they are of enormous extent and great depth, but in the ordinary or typical cases they are shallow excavations, from two or three feet to fifteen or twenty. Soft clays are seldom worked with very deep pits, because of the danger of their caving during rains. It is practicable in some few cases where soft clay of one kind occurs in a very thick bed to make a deep excavation with banks sloping on the angle of stability of the clay when wet. But where the clay sought at deep levels is desired, and a heavy stripping is to be removed, then the open pit is no longer an economical method.

An open pit working may, then, be understood to be any kind of a cut in the surface from which clays can be won, provided that it involves no blasting, or but very little, to make the clay workable by the ordinary dirt moving tools and apparatus. It may be a straight cut through a plain or ridge, or a crescent-shaped side-hill cut, or a shallow superficial pit of great area, or a steep-sided, bowl-shaped cavity, or even a vertical-walled shaft of large cross-section—all are entitled to the name of open-pit workings.

The open pit is the most difficult form of all clay deposits to operate, owing to the fact that the deposit, in the nature of the case, must be subjected in all stages of working to the influences of daily weather changes and frequent storms. Rains not only usually drive the laborers from the field, but, if of any duration, so wet the clay that it becomes too soft or sticky to work it when delivered to the factory. The above conditions are to be expected occasionally during the summer months,

but from about November to April in states north of the fortieth parallel of latitude it is usually impossible to operate except at a prohibitive cost. This entails that the manufacturer shall provide storage sheds, which he is obliged to fill during the summer months. These must be of such a capacity as will tide his work through the months in which he is unable to gather clay from the field, or else it involves the stopping of the plant for from a quarter to one-half of the time.

Winning clay from open pits may be discussed under two headings, viz: (1) The actual operations of the clay digging or excavation, and (2) the subsidiary operations of draining the works, timbering, track laying, protecting from weather, etc.

The excavation is accomplished by pick and shovel work, by plow and scraper work, by clay-gathering machines, and by steam shovel work.

Pick and Shovel Work.—This is the most elementary method in use in clay works among the civilized races. It is the most expensive method of all in labor, and the least expensive in equipment. The tools are the pick and shovel. It is in use in surprisingly many clay works today, and it is not uncommon to see clay handled more than once by this method before it reaches the preparing machinery. The costliness of the method depends very largely on the following two factors:

1. The hardness of the clay, whether requiring much picking or not. Some require no picking. Others must all be picked before any shoveling can be done.
2. The nature of the pit-bed as a shoveling-floor, whether smooth or rough, and also the nature of the material to be shoveled, whether fine and sandy or coarse and lumpy, or flat and plate-like.

In general, the use of this method is caused by lack of capital, but there are cases where the clays contain impurities that can be rejected by hand-digging and not by other methods, or when different layers of clay must be kept carefully separated, as they are reached successively in the pit. In such cases, pick and shovel methods cannot be replaced by any other.

Spading.—A modification of ordinary pick and shovel work, known as spading, is used in some clays very successfully. It requires a clay of wet, cheese-like consistency, comparatively free from bowlders or foreign matter which would stop the cut of the spade. Such clays can often be worked with vertical walls and stand for long periods without caving. This method of working is not uncommon among the plastic clay beds of New Jersey and the Atlantic coastal plain, but among the older and consolidated clays of the Mississippi Valley it is not very commonly used. In only two instances, among the present roofing

tile plants of the country, is this method used: viz., at the Detroit Roofing Tile Company, Detroit, Michigan, and the Ludowici Celadon Company's plant at Ludowici, Georgia. The former clay bed is of glacial origin, and has the peculiar, tough, cheese-like nature which makes spading the logical mode of extraction. (See Figure 56.) One of the best examples seen of the spading system was at the Ludowici, Georgia, plant of the Ludowici-Celadon Roofing Tile Company.

Fig. 42—Clay Pit and Transportation System at Ludowici, Georgia.

The clay in this pit is of a very soft, fine-grained, plastic nature, having a depth of about six feet, and at the bottom resting on a bed of fine white sand. Quoting from Veatch, "The Clay Deposits of Georgia":

"The clay used is located near the factory on Jones Creek, a small tributary of the Altamaha river. The deposit is of Pleistocene age and is probably the equivalent of the second bottom or Columbia deposits of the Chattahoochee, Ocmulgee and Savannah rivers, and was deposited during a high stage of water in the Altamaha river. The deposit is about six miles distant from the river, but is at the present time occasionally flooded by back-water from the Altamaha.

"The clay is four to seven feet in thickness, has practically no overburden and is underlain by a white water-bearing sand. It is yellowish, red, and bluish in color; a mixture has a yellow color, is very fine-grained, stiff and plastic. It is free from pebbles, coarse sand or coarse rock fragments. The clay is noticeably bluer, stiffer and more plastic around the roots of old stumps, a change evidently effected by organic acids from the wood. The deposit is mined in small separate pits, with pick

and shovel; water accumulates rapidly in the pits and drainage facilities are poor, and in winning the clay a clay partition is left between the pits, to prevent the water which accumulates in the abandoned pits from flowing into those which are being worked. The clay is hauled to the plant, which is about one-half mile distant, in cars pulled by mules.

Unless the method of winning clay by shovel is properly carried on, very annoying results may be expected. For instance, if a pit is not uniform from top to bottom, i. e., there are certain layers or strata varying in physical properties from the bulk of the deposit, and is taken off layer by layer, there will be a very variable product in the finished ware.

Should this same pit be worked in benches, loading into each car a certain number of spadings each time from the various benches, a uniform product will be the result.

While it is possible to get a very uniform mixture of material by the shovel method, this point is most often neglected and little attention is given to the order in which the strata are loaded.

The Plow and Scraper Method.—This simple and everywhere familiar mode of excavating and moving earth is available as a mode of winning soft clays. The limit of hardness which a clay may have and still be amenable to plowing and scraping is usually known as "hard-pan." Hard-pan is commonly bowlder clay, so compact as to be almost impossible to plow and so full of stones as to keep a plow jumping out of the furrow or stalling. Shales cannot be plowed or scraped, except on their weathered surface. When the full hardness of even a soft shale is reached, the method becomes an ineffective one and hard shales cannot be worked in this manner at all.

The plow and scraper method is used more as a means of stripping earth or clays from the surface of the desired stratum than it is for the winning of the stratum itself. The removal of from a foot or two up to eight or ten feet of undesirable earth and clay from a good stratum is within the limits of ordinary commercial conditions, but for regular strippings of more than ten feet in thickness, the use of a cheaper system than the plow and scraper becomes necessary, and hydraulic jets to wash the clay away or steam shovels or mechanical excavators are used.

It will be observed that this system is finding its chief use as an auxiliary to some other mode of winning. The materials stripped are usually *spoil* which goes over the dump bank or is used for grading purposes. But, if the materials removed are in themselves fit for use, their winning can be accomplished at a comparatively low cost. In the matter of securing a homogeneous daily output from a bank composed of strata of different properties, this can be accomplished, as in hand work, but only by the daily exercise of care and pains. In general, men dislike to plow up hill or down hill, and in a bank with

horizontal beds the strong tendency of the men would be to take it off layer by layer, in the very way that makes the most serious trouble in the factory. By working the bank on an incline, so as to cut all strata at an oblique angle, or by taking it out in benches and mixing the products of the benches in the ratios of their occurrence, an output may be obtained of quite uniform character from a bank of variable composition. The extra supervision to secure this result and the little daily losses of time in waiting for the different loaders to deliver their quota in turn, will surely make the method quite a little more costly than that of straight stripping work.

One of the troubles incident to this mode of working a plastic clay pit is in the matter of wet clay after a rain. The use of horses and plows, etc., makes the pit muddy at once and the clay is sure to be so sticky as not to be fit for immediate use or for storage. A lump of plastic mud will stay wet a long time if buried under a pile of similar material. This difficulty constitutes a very real and important restriction to the use of this plan for storing clay in sheds for winter use.

The Clay Harvesting or Gathering System.—This plan is devised to meet the objections raised against the plow and scraper system in the preceding paragraph and is used by those of the industry who are not only obliged to win a supply of clay for the daily consumption of the plant, but in the summer months must provide a supply sufficient to run their plants throughout the winter. This means that a large amount of material must be handled within a short period of time.

Two plants, those of the Ludowici-Celadon Company at Chicago Heights, Illinois, and the National Roofing Tile Company, at Lima, Ohio, are making use of a very excellent machine for the purpose, the proprietary name of which is "The Quincy Clay Gatherer." It is made by the Central Iron Works, at Quincy, Illinois.

This machine consists principally of an open-topped drum or barrel, supported between two wheels, which in turn cause a set of scrapers to revolve around the drum. These scrapers scoop up the previously loosened clay, and carry it on their trip around, until upon reaching the opening at the top of the drum the clay drops from the scrapers into it.

A drive of twenty or thirty yards is sufficient to fill the drum, which holds approximately one cubic yard. The scrapers are then raised and the load is hauled off to the storage shed or grinding room, where the drum by means of a trip or latch is caused to revolve with the wheels. As soon as the drum has made about one-quarter of a revolution, the clay begins to empty out of the open top and by the time the complete revolution has been made, the entire load has been discharged.

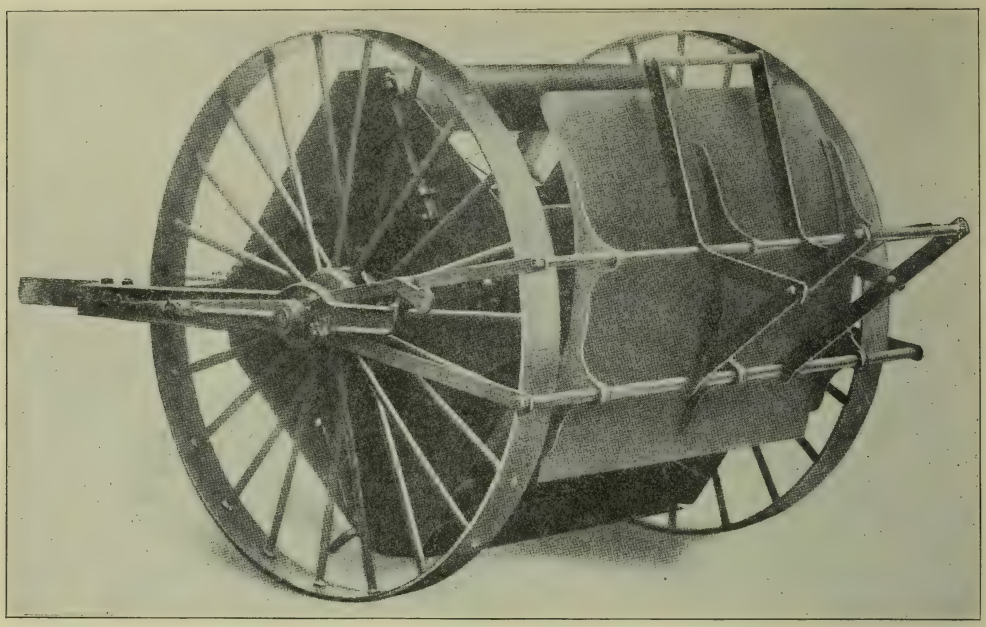


Fig. 43—Quincy Clay Gatherer.

This method of winning clays is to be commended, owing to the fact that the layer of clay cut off from the surface of the ground is thin, only an inch or two, and even if the field is wet, after rains, the use of a drag or harrow to cut up the surface and air it, and the removal of the aired clumps of clay in a series of very thin cuts, enables clay to be gathered with but little interruption from summer showers, and still procured in excellent condition for storing. The method excels that of the plow and scraper only int his point.

It is an excellent mode, also, of obtaining a uniform mixture or average, where the clay formation occurs in parallel strata or beds, if it is properly worked, but requires the same careful supervision before described to see that all levels of the pit are being worked simultaneously.

The gathering, to be properly done, requires the proper opening of the field, or pit. This is done by working the field on an inclined plane, having a depth equal to that of clay stratum to be worked. To properly gather the load of clay, the scraper is started at the bottom of the pit, driving either straight or diagonally to the top of the pit, then turning round and driving down the low sloping side again. A load so gathered represents an accurate mixture of the deposit over its entire cross section.

The sampling does not cease with the loading of the material, but is again perfected at the unloading point. As described before, the

load is not dumped at a single point, but is distributed over the storage shed floor for a distance of ten or fifteen feet.

It will be understood, though, that the advantage of the use of this clay gathering device is restricted. It can only produce a strict average of the clay, where the latter occurs in parallel strata. In a bed of folded, or unconformable, or irregularly mixed clays, such as are often found in the more recent clays, this system would lose much of its efficiency as an averaging device, though it could scarcely be improved upon by anything else except careful hand winning. It might possibly be used on very soft shales, provided the bank could be opened over a area large enough to properly carry on the work.

The use of the clay gatherer is much more applicable to the glacial and alluvial clays, whose bedding is always horizontal. In working these soft clays it is necessary to precede the gatherers by about half a day's work with a tool known as a drag, or plow, which loosens the clay to a depth of about two inches.

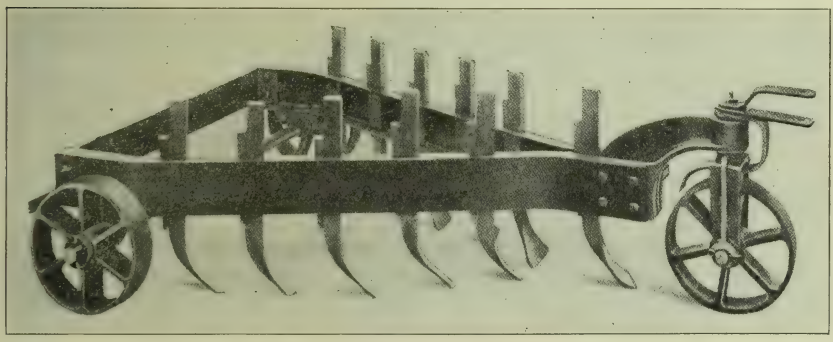


Fig. 44—Quincy Clay Plow.

This machine not only loosens the clay, but puts it into a condition such that it will become more or less dry by the time the scrapers reach it.

It will be found next to impossible to work wet or sticky clay by the clay-gatherer. The clay will pack in the drum, and give much trouble in dumping.

The drag, or plow, shown in Figure 44, consists of a triangular wooden frame about five feet on a side, supported or carried at the three corners by small wheels. Distributed along the sides are small plows, or teeth, such as are to be seen on the ordinary farm cultivators. These teeth extend about two inches below the bottom of the wheels that carry the frame. Three horses are required for the plow, which cuts or loosens a path of clay about five feet wide. The action of the plow is similar to a harrow, except that its plows have a little better cutting power than a harrow.

Fig. 45—Quincy Plow in Action at Pit of Ludowici-Celadon Co., Chicago Heights, Ill.

Fig. 46—Quincy Clay Gatherer at Work in Pit of Ludowici-Celadon Co., Chicago Heights, Ill.

The Steam Shovel.—Another method of winning clays very widely used in both soft and hard clays is the steam shovel. The general nature of this machine is so well known that it will not be necessary to describe it here. It is a notable fact that not in a single instance in 1908 was the steam shovel being used to win clays for the roofing tile industry.

This state of affairs can easily be explained when we consider that the amount of raw material consumed by a roofing tile plant is relatively small when compared with the brick or sewer-pipe industries. For instance, if a roofing tile plant was producing one hundred squares per day, this would require in the neighborhood of fifty to sixty tons of material. Should this same amount of material be made into building bricks it would produce approximately 12,000 to 15,000 of standard size and much fewer of paving brick. This would be considered a very small plant, and for the tonnage required no one would think of installing a steam shovel. The investment and the expense of maintaining and operating the shovel would be entirely out of proportion to its capacity. On the other hand, a roofing tile plant of a capacity of 100 squares a day would be considered of very fair size. It would not be economical to use a steam shovel equipment for a roofing tile plant unless the plant were a very large one.

WINNING OF SHALES.

As stated before, of the fourteen plants visited, ten are using shales, nine using open pits or quarries and one drifting or mining into the hillside.

Shales differ from glacial and alluvial clays in the matter of being hardened to a point where they can no longer be loosened by the spade or shovel, and generally not by a pick with any economy. The hardened clays or shales almost always require blasting to break or loosen them from their present mass, and even when thrown in a pile of loose material by a blast, they generally come out in such heavy, coarse lumps that a further recourse to the pick, sledge and bar are required to break them down into sizes accepted by the crushing machinery. Often auxiliary shots, or "pop shots," are employed to break the bigger pieces after a big blast has thrown down the face of a shale pit.

Before studying the methods of quarrying shale, it would seem best to first fix in mind what conditions are to be found at the average shale bank in use.

In the majority of cases the bed of shale will be attacked at some point above surface grade—that is, at a higher level than the plant or surrounding territory. Of course, shales may occur at any level with regard to that of the plant, but the difficulties of operating any clay pit below grade are so much greater than one with free drainage that clay

workers generally hunt for an exposure of the proper material at the proper elevation instead of attempting to work one at a level too low to permit natural drainage. Of course, in some localities, where shales are scarce, the deposit is worked where it can be found, and a low level is accepted as one of the natural obstacles to be met and overcome.

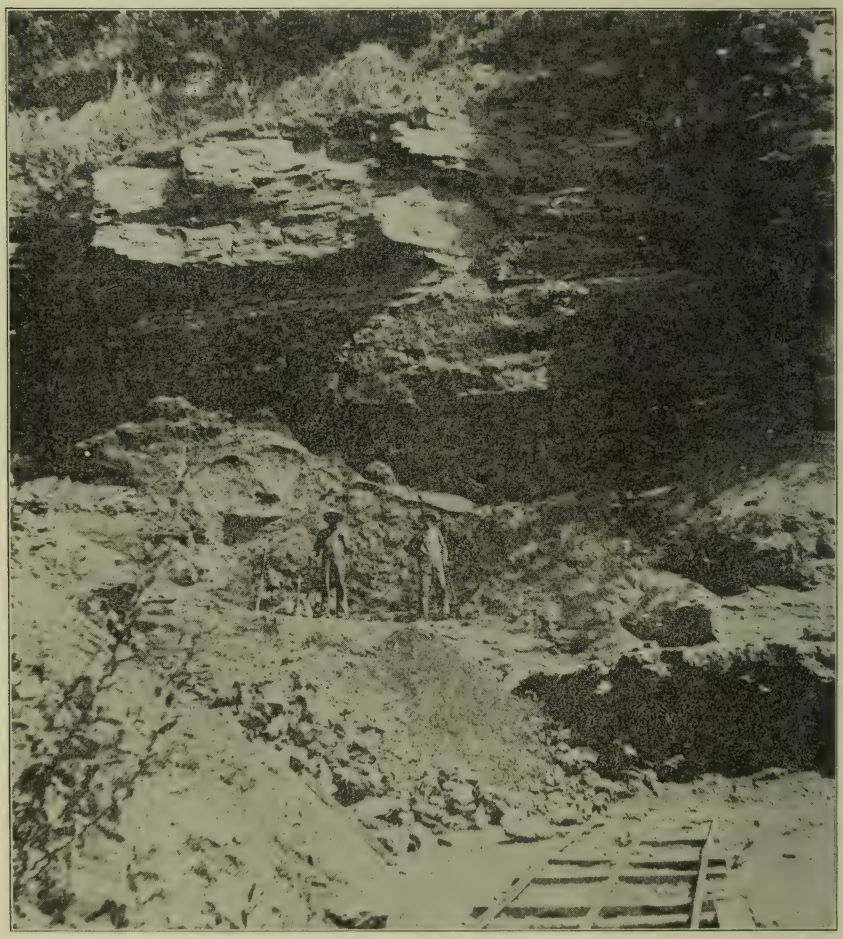


Fig. 47—Shale Bank of the United States Roofing Tile Co., Parkersburg, West Virginia.

Shales are usually well stratified, but in some cases, as at the bank of the United States Roofing Tile Company, at Parkersburg, W. Va., the stratification of the shale is very slight or has become partially obliterated.

At the plant of the Huntington Roofing Tile Company, Huntington, W.Va., are to be found two shale banks in use. The lower, or No. 1 bank, (Figure 48) contains an extremely fine grained, well stratified shale, quite

soft and easily dislodged. Their No. 2 bank is made up of a very sandy shale, well stratified and very hard, breaking out or blasting in very large blocks, as seen in Figure No. 49. On the left hand side of the same figure can be seen a large pile of slaked or weathered shale. This company was in 1908 the only roofing tile concern in the United States that was weathering its raw shale.

During the summer months of each year large amounts of the shale are blasted loose, and then wheeled out and heaped up in a windrow or long pile three or four feet deep, and allowed to remain until the following year. This allows the natural agencies to break down the massive blocks of hard material, which would otherwise have to be done by hand or machinery. In this particular case the clay is improved in another way, viz., the soluble salts of lime and magnesium that are present in the parent ledge are leached out and carried away by the rains, leaving the shale much improved in quality.

Stripping.—By observing the pictures of the various shale banks shown in this report, it will be noticed that the overburden ranges in thickness from a foot or so, up to many feet. The removal of this overburden, if large, becomes a serious source of expense, and a problem in the management of the quarry. In most cases, the stripping is done by plow and scraper. If the road to the wasting point is short, the small dump-scraper is used, but if the distance is over 100 feet, the wheeled scraper is the better and more economical machine to use, on account of carrying much larger loads.

At none of the roofing tile plants has the use of hydraulic jets been taken up, in removing the stripping or overburden. What was said of the use of the steam shovel as a mode of winning for roofing tile plants applies to the use of the hydraulic method of stripping, in some degree, i. e., the amount of material to be moved will not ordinarily justify its use. This does not apply with equal force, however, for while a steam shovel of the smallest size would be much too large for an ordinary roofing tile plant, it is possible to make hydraulic installations on almost any desired scale.

The method consists in the application of streams or jets of water from a hose pipe, under high pressure, usually 100 pounds per square inch at the nozzle, against the face of the soft clay. The water will burrow its way into the clay, and wash it into a slime or thin fluid, which will flow off through runways. The labor of this system is at a minimum—the nozzle-man is the only one employed for hours at a time. But the system requires the use of great amounts of water and the service of an engineer to provide it, and also requires frequent changes in the pipe-lines, the runways, the receiving ponds or fields on which the slime is distributed, etc.

12—G. B. 11—1,000.

Fig. 48—Clay Pit No. 1. Huntington Roofing Tile Co., Huntington, W. Va

Fig. 49—Clay Pit No. 2. Huntington Roofing Tile Co., Huntington, W. Va.

When all such costs are included, there is no question but that this mode of moving sand, gravel, clay, etc., is still far below any other method. It requires, however, conditions that are not always found, viz., adequate water supply, and a place to distribute the materials used —the latter is often more serious than the first. The method may be said, therefore, not to be susceptible to general adoption, though exceedingly cheap where the conditions favor its use.

At the Parkersburg plant the stripping is done by pick and shovel. The bank is on the side of a very steep hill, so that it is only necessary to loosen the overburden and give it a start with a shovel and it falls to the bottom of the pit, where it is loaded into dump-cars and sent down the incline to be used as grading material in the low lands below.

In the ordinary shale bank, the usual method of procedure is to first uncover or strip the surface of the shale over an area which will furnish a year's run. This is mostly done, as stated before, by teams and scrapers. In the work of developing the bank at first, this preliminary stripping is often done by pick and shovel. This is continued until a working-face has been exposed, that is, an exposure of the shale for some distance laterally along the out-crop, and having a vertical section equal to the depth of the stratum, or if this be too great, so much of it as may be desirable to work. There is naturally a good deal of extra stripping to be done in opening up the ordinary shale pit, before the conditions of quarrying become normal. The soft or weathered edge of the shale is usually to be removed, and an excess of surface-clay or stripping has to be taken off. Gradually, as the workings progress back into the hill, the face of the stratum exposed becomes normal, i. e., the proportion of surface-clay, weathered shale, and hard unaltered shale becomes more nearly constant.

The height of a shale stratum which can conveniently be worked in one bench is not over twenty or twenty-five feet. The disadvantages of too high a face are great—it is dangerous, when caving, and inconvenient to get up and down, in loosening hanging pieces, etc. A thirty-foot bank is generally better worked in two fifteen-foot benches, rather than in one of thirty feet.

Quarrying.—The actual operation of quarrying differs from hand-digging in the use of explosives. Everything else is common to the two modes of working. Or, rather, after a shale has been blasted, its loading is practically the same as hand digging, though the proportion of use of bar, sledge, and pick is greatly increased and the use of the shovel is somewhat reduced. In many cases men will lift much of the shale in large lumps by hand instead of by shovel.

Blasting.—The work of disrupting rocks or earth by explosives may be divided into three parts, viz.: 1st, drilling or preparing the hole for the reception of the explosive, 2nd, the loading, or preparing the explosive charge, and equipping it with ignition or firing mechanism,

and 3rd, "shooting" or exploding the charge. For drilling, and in fact throughout this work, two men usually work together as a crew.

Drilling.—Drilling holes in rocks at its best is a specialized business, with large mechanical equipment and room for the exercise of much skill. In general, however, drilling is done in four ways: 1st, by hand; 2nd, by augers turned by hand power, with or without a mechanical feeding appliance; 3rd, rotary power-drills; 4th, percussion power-drills. The choice of a method for any given case depends on the amount of drilling to be done, the hardness of the rocks, the depth and diameter of the holes, the necessity or advantage of speed in drilling, the wetness of the strata, etc. In general, clay and shale is prepared for blasting by the first two methods, especially in the roofing tile business, for the amount of clay needed would make the installation of a modern drilling plant an absurd extravagance.

Hand Drilling.—The tools required for this work are: a five or six-pound sledge-hammer, usually three drills or "spuds," varying in length from three or four feet in the shortest, up to ten or twelve feet in the longest. It is necessary to have these various lengths to suit the convenience of the men as the hole deepens. The drills are of tool-steel, ⅞-inch to 1¼-inches in diameter, drawn out at the lower end into a fan-shaped bit or cutting-point. A bucket of water, a dipper, a brush or "swab" and a scraper for cleaning out are also needed. The drillers most often provide their own swab by cutting a young sapling (of hickory preferably) an inch or so in diameter and about ten feet long. Then by pounding or mashing the thick end of it with the sledge, they fray it out for a length of six or eight inches.

The actual process of drilling a hole for a blast is a process similar in nature in all materials, but varying greatly in difficulty or the amount of energy required. In the softest clays which need the use of explosives, the drill can be driven into the clay by merely lifting and dropping it, or "churn-drilling." In fact most shale clays can be churn-drilled.

When the shale is quite hard, the drill requires the use of more power. In drilling a vertical hole, one man takes the sledge, the other the shortest drill, which he holds plumb at the point previously selected. The man with the sledge, called the striker, proceeds to strike the drill with quick, sharp blows, while at the same time the driller between each blow of the sledge raises the drill a short distance and during the same interval twists the drill through an angle of from 30 to 40°. Each four or six blows therefore cuts the bottom of the hole over its entire area, creating numerous small chips of the loosened rock.

They proceed thus until they have drilled down through from several inches to a foot or so of the shale. A dipper of water is now poured down the hole and the brush end of the swab is inserted, and after a short churning up and down is withdrawn laden with the newly made mud. On withdrawing, the swab is given a sharp blow or rap

over a block of wood or a stone, thus freeing it of the accumulations; possibly a little more water is added, and the work repeated until all the mud made from the drillings has been withdrawn. The drill and sledge are now brought into play again. Thus the work proceeds, until the desired depth is reached, usually not exceeding ten or twelve feet. The hole is now dried and cleaned out as carefully as possible, by pouring down a handful or so of dry clay at a time and withdrawing it in the spoon or scraper. In wet clays, or shales permeated with water-bearing seams, this drying of the hole is very difficult to do, and recourse is had to a cartridge of oiled or soaped paper, which will slip down the hole quickly and permit a shot to be gotten off before the water soaks through the paper.

Auger Drilling.—This method is applicable to clays and shales of all degrees of hardness. It is limited to rocks of about that grade, such as coal, gypsum, talc and soft limestones, and is inapplicable to really hard rocks like sandstones, granites, etc.

The simplest form of this work is a double brace, or handle devised for twisting the auger around an imaginary center, using both arms to maintain the motion and the chest to supply the pressure of the drill against the rock. This is applicable to soft clays and only the softest shales.

The common forms are frames, arranged to fasten upright or inclined between the floor of the quarry or mine and some point above it, in the face of the rock, or the roof of the mine. This frame is braced in position by screws and guys. The auger is mounted on the end of a long screw or threaded steel bar, which is passed through a nut fastened in the frame described above. By turning the screw, it feeds itself through the nut at the rate prescribed by the pitch of its threads, usually one-eight of an inch per revolution. The turning is done directly by a crank or handle on the end of the screw, or by the intervention of gears, with two or three different rates of motion, if the rock to be drilled is fairly hard. The power is supplied by the driller himself.

These machines are of wonderful service in mines, where the roof and floor offer facilities for fixing them in position readily. They will make holes at almost any angle, but most easily when nearly horizontal. They are used, but less readily, along the foot of a shale bank, in an inclined position, and for making horizontal holes or holes inclining downward. They are practically useless for making vertical holes, in open workings. A man will make in a six foot hole, 1¾ inches or 2 inches in diameter, in ordinary shale in from twenty to thirty minutes, and often much quicker.

Rotary Power Drills and Percussion Power Drills.—These may be left out of consideration, as they are only suited to very large quarries or to rocks of greater hardness than shale clays. Some few brick works

in the country are large enough to make their use economical, but certainly no roofing tile plant could do so.

Springing the Hole.—This practice is only used in rather soft rocks or such as are penetrated with many fissures for the escape of the explosion gases. It is done by firing a small piece of dynamite—usually a section of a stick an inch long is enough—at the bottom of the hole. It does two things. First—it dries out the hole by the hot gases liberated there. Second—it makes a cavity usually pear shaped or spherical in shape, which acts as a receptacle for the explosive. It thus makes it possible to get in a much larger quantity of explosive and also to concentrate it in a relatively large mass, instead of spreading it up and down a large vertical range.

Choice of Explosive.—There are two classes available—the slow combustion powders and the instantaneous or chemical explosives. The powders burn very rapidly it is true, but nevertheless they generate their explosion by ordinary combustion. The chemical explosives generate their explosion by molecular decomposition, not like combustion at all, though it is accompanied by heat. The difference between the two is very great. The powder is slow, relatively, and weak in its effects. The chemical explosives, represented by nitroglycerine and dynamite, fulminates of silver and mercury, etc., work with much greater speed and much sharper or concentrated effect. This difference decides the use of the material for its proper place. Soft, loose, uncompacted, or "leaky" rocks, like shales, need powder. The effect of dynamite is dissipated too much. But hard, dense and "tight" rocks need dynamite. Either kind will of course do something in any place where used, but their most efficacious use is as above set forth. Many shale drillers use a mixed charge, partly dynamite to "start" the explosion, and the balance black powder to "follow it up," these terms referring to the difference in rate of action. The economy of thus mixing charges is open to question.

Altogether, the technique of blasting, though simple, is nevertheless considerable, and there is room for the acquirement of great personal skill in handling the explosives judiciously. A good blaster will do three or four times as much work with a box of explosive as an inexpert one.

Loading.—The next step is to get the charge properly into place in the hole. The desired quantity, usually such as will about half fill the hole, is dropped in, a water-proof fuse tape being first let down the hole until it nearly touches the bottom, then is cut off from the reel or main supply about a foot above the top of the hole. Then fine dry dirt or clay is put in on top of the explosive and by means of the tamper or reverse end of the drill, is carefully compacted. More is added and tamped at short intervals, damp clay being used after the first addition. When the hole is entirely filled, the fuse is lighted and the men re-

treat to a safe distance. Usually a minute or two elapses before the explosion. Where dynamite is used extensively, an electric sparking apparatus for igniting a charge is used very commonly. It has the advantage of not being subject to dampness, and also of making it possible to ignite any number of charges simultaneously. For small plants, it is not needed, though used by some on account of the somewhat less danger of premature or delayed blasts. In most cases it will be found that the bottom of the bank has been blown out, and the mass above has either tumbled down at the foot in a rough pile, or is loosely hanging, ready to fall with a little assistance from the bar or pick.

In cases where the shale is hard it will be found necessary to sledge apart or break up the large blocks before loading into wagons or cars.

In favorable cases it is not unusual to dislodge from fifty to several hundred tons at a single shot, depending on the size of the bank and many similar conditions.

In Figure No. 48 can be seen the effect of a newly-made blast. All of the loose material behind the wagon was brought down by a single shot. The tamping rods, drills, and other tools for the work, can be seen on the bank above the fall of shale.

It will be readily understood that the work of shooting out the shale for a roofing tile plant each day is only a matter of one or two well-placed shots.

It is not unusual for two, three, or even five holes to be drilled and fired at the same time, thus providing a week's supply of material at a single operation.

The Placing of Shots.—In this subject lies the most of the skill of the quarryman, and one man exceeds another in the judgment he displays in placing shots where they will do the most execution. The art cannot be learned except by practice and experience, but many who have practice and experience in plenty never make expert blasters. The quarry boss usually supervises this himself, and aims to have each shot so placed that, when fired, it will expose a new point of advantageous attack. The nature of the rock, its seams and openness, its cleavages or lines of break, its tendency to hang or merely loosen up without lifting out of its bed, its rate of use at the plant, the extent to which it hurts it to be wet or caught by rains after blasting—all these and many more things have to be considered in laying out the work of a quarry. A good quarry boss can tell what his plan of campaign is for days ahead of his work, and has provided in this plan for the contingencies of stormy weather, shortage of men, etc.

Clay banks are generally worked in a long line, approximately straight, or on a gentle curve, or else they are worked with two faces, one at right angles to the other. Some, of course, are erratic in shape, on account of irregularities of deposit or local obstacles.

MINING.

The third method which was found in use in the winning of roofing tile clays was mining. The formation mined was a shale of the Coal-Measure period, at the plant of the Murray Roofing Tile Company of Cloverport, Kentucky. The shale bed here is capped with a ledge of limestone, making a good safe roof whenever the cover was deep, but around the out-crop the fissures of the limestone had been widened by the percolation of rain water until the stratum was cut up into blocks. These blocks, if undermined, completely or largely, then became very difficult to hold up, and hence dangerous.

Fig. 50—Entrance to Shale Mine, Murray Roofing Tile Co., Cloverport, Kentucky.

The shale stratum mined was about twelve or fifteen feet in thickness. The mine was situated closely in rear of the plant, and the tram car haulage from the mine led directly into the stock-room of the factory.

The mining of a stratum of moderate thickness, five to ten feet, is simply a modification of quarrying. The modes of blasting, loosening the material, sorting and loading it for transportation are all the same, or differ only in minor details from ordinary quarrying outdoors. But there is introduced an entirely new set of factors, viz., the support of the strata overhead to prevent caving in, and the conducting of ventilating currents into the mine and out of it, to make the air pure and healthful for man and beast. The problems of haulage and drainage are not much different from the same factors outside.

The timbering or supporting of the roof or hanging wall, is a heavy factor of expense in nearly all mining. This factor varies with the thickness of the stratum mined, for the longer the timbers must be to reach from floor to roof of the chamber, the heavier and more expensive they are.

The ventilating of a mine also calls for the use of fuel, either burned directly in the old-fashioned ventilating furnace, or indirectly in steam engines or gas engines, by which fans are driven, forcing pure air in or sucking vitiated air out. The ventilation also requires the driving of special passages, break-throughs, over-casts, and the erection of doors, stoppings, brattices, etc., for direction of the air currents past the old and abandoned workings, and into the new workings where they are needed. To properly ventilate a large mine is a problem requiring high-grade skill and experience.

It is obvious that to work in cramped quarters, in artificial light, to provide an artificial air supply, to provide timbers for preventing the beginning of caving in, in addition to the normal expenses of quarrying, draining, loading and handling, is bound to make mining an expensive form of winning. It cannot be otherwise. Its average cost per ton may be said to run from about twice to three times what the quarrying of the same material in the open would be.

There are, however, some advantages to offset the extra cost. The ability to work the mine all the year around and deliver a constant supply of material in the same condition as to dryness, in all kinds of weather, is a matter of the highest importance to a clay plant. The use of the mining method of winning ordinarily does away with the need of a storage shed for housing a winter's supply, and for the investment of large sums of money in clay which has to be stored months before it can be used. It also provides, ordinarily, a more regular daily operation of the plant with far less variation from day to day than when clay direct from an open pit is used, since it does away with wet and muddy material and delivers its product in the same state all the time. More regular operation means a larger output with the same force of men. So that, while mined shale is more costly than quarried shale, it does not necessarily follow that the output of the plant is costing more in the long run.

Mining shale is more difficult in general than mining fire clay, or coal, or other formations, on account of the thickness of the strata and the extraordinary length of timbers required. For this reason, a shale mine is very rare, and represents conditions seldom met, while the mining of fire clays and kaolins is quite the usual or common method of working these clays.

Draining Clay Pits.—Clay pits, whether open or under ground, and in soft or hard clays, very commonly are so situated as not to be self-draining. On side-hill excavations, the problem of draining is usually

merely a matter of a little ditching. But, on level grounds, where clay pits are really pits in the true sense of the word, or in mines where the formation dips away from the opening, the problem of keeping the workings dry is a factor to be seriously considered.

There are a considerable variety of means available. The following were observed in actual use in clay pits of the roofing tile companies of this country.

1st. Centrifugal Pumps.—This style of pump is capable of handling the mud and gravel that is sucked in with the water, without the cutting and clogging effects that occur with a piston-actuated pump.

The Ludowici-Celadon Company's Plant at Chicago Heights, Ill., has in use a motor-driven centrifugal pump that throws, when working at full speed, a solid six inch stream of water. This very large and powerful installation is made necessary on account of the large size of their clay-pit, some six or eight acres; it clears it in a reasonably short

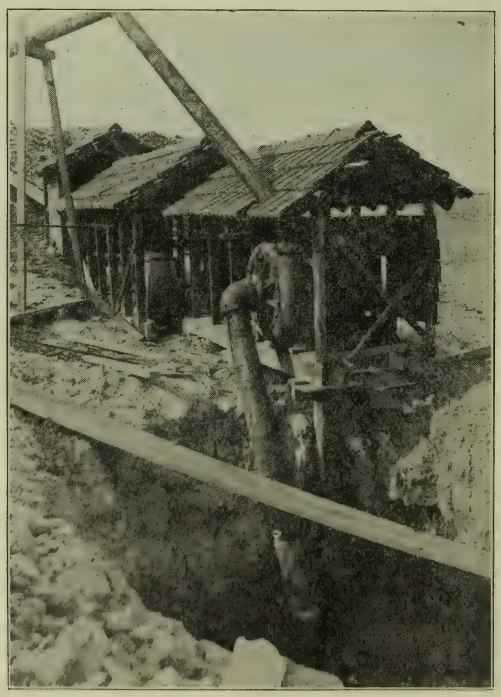


Fig. 51—Motor-Driven Centrifugal Pump, in Use at Clay Pit of Ludowici-Celadon Co., Chicago Heights, Ill.

time. The above company is using the same kind of pump at their "Dixie" plant at Ludowici, Ga. For large plants, or for large clay pits, or for small but very wet clay pits, the centrifugal pump is the most

efficient mode of draining. Its ability to handle anything that will flow through a pipe is a great point in its favor. It requires an expensive installation.

2nd. Steam Ejector.—At another plant, where the pit i very much smaller and the water to be moved correspondingly less, a steam ejector is used to drain the clay field. The ejector, while very cheap in first cost, is of low capacity, and at the same time is a most expensive and inefficient way to use steam. Supplying it with steam is usually inconvenient and expensive, requiring a small boiler at the pit and a man to tend it, or else long expensive pipe lines from the main boiler house, with accompanying low efficiency of the steam by cooling and condensation enroute to the pit.

This method, however, is of great utility in many places where but little water is to be removed, and steam is available at no great distance. It is very simple in operation.

3rd. Bucket Elevator.—Another method of doing the work is by the use of the ordinary bucket elevator. The elevator suited to this class of work would preferably be that of the link belt or chain variety. The ordinary rubber or canvas belt would not answer so well on account of the continual soaking in water, and the cutting action of the sand and gravel.

By using large cups placed near together on the chain, a very large amount of water could be raised in a given time. The power to operate a rig of this type would best be supplied by a small gas or gasoline engine, or by a small portable steam engine as second choice. It might even be operated by horse power.

4th. Farm Windmill.—The use of a common farm windmill has been successful in draining a small clay pit for many years at Groveport, Franklin County, Ohio. The pit supplies ample clay for a moderate size roofing tile plant, and is located on a river bottom, where water is collected freely. As stated before, draining shale banks is usually an easy matter as most of them are side-hill workings which can be well drained by simple ditches.

5th. Suction or Piston Pump.—At one shale-pit, that of the Western Roofing Tile Co., at Coffeyville, Kan., the shale lies at a level below the general surface of the prairie, and hence artificial drainage is necessary. At this plant, a three horse-power gas engine is employed to operate a regular suction or piston pump which is placed at a sump or collection hole at the lowest point of the pit. The water from the rest of the pit is brought here by ditches, and the pump delivers it to a point outside of the workings.

At the one company which was mining its shale, the Murray Roofing Tile Co., of Cloverport, Ky., the strata happen to be dipping away from the plant, so that the drainage of the mine tends to collect always

at the farthest point of the workings. This is a common but unfortunate condition in mining, for it means the working face of the mine tends to be wet, while the old or abandoned workings are usually dry. The only available method to drain such workings is to put down sumps connected with the working faces of the rooms by shallow ditches. By pumping the sump dry daily or continuously if necessary, the working faces may be kept reasonably clear of water. Sometimes in outlying points, it is necessary to use a water car, or water-tight box or tank, which is filled by pumping or bailing the water at the working face and emptied either outside the mine or in a sump or ditch connecting with the outside. This is an expensive way, but often cheaper than a pipe line and power pump.

Underground workings are very apt to be much worse to drain than surface pits. The latter are subject to evaporation by the wind and sun's rays, and only fill up from rains, while mines are usually fed by springs or underground seepage which runs constantly. So that the provision of a steam pump, compressed air pump, electric motor driven pump or gas engine pump is apt to be a necessity. This condition exists at the Cloverport plant, which uses a steam pump for this purpose.

Clay Storage.—The plant that has for its source of material an open shale bank is in a much better position for a continuous supply of clay than one depending upon an open clay-pit, owing to the fact that the rains do not interfere nearly so much. The shale is much harder and more compact, and does not soften and become difficult to shovel or grind as a plastic clay does. At the same time, after a long,wet winter, it is often found that the shale with its overburden of plastic stripping or of partially weathered shale has become too wet to work. It possibly may not be enough to prevent its being ground, but enough to greatly interfere with its being screened.

There are, during the year, many days of inclement weather, in which men are loth to work, and even though they work their output would be far below the average. To overcome the above conditions, nearly every roofing tile plant using shale has made provision for the storage of dry shale during the summer months, in order to carry them over the stormy days, or to enable them to mix dry shale with the wet sticky shale fresh from the quarry, which is certain to be encountered during the spring months.

At some of the plants, provision is only made for a supply equal to a few days' run, or even a few hours' run, while in others a supply equal to six or eight weeks run is housed. Inasmuch as this matter of storage of clay is one intimately concerned with methods of transportation of the clay from the pit to the plant, it may properly be considered in connection with that topic.

TRANSPORTATION AND STORAGE OF CLAY.

The method of transporting the clays from the pits or mines to the point of their storage or use is a matter much influenced by local conditions. Without attempting to discuss all the modes by which such work is done, those which were actually found in use were as follows: (a) Wheelbarrows, (b) Common scrapers and wheeled scrapers, (c) Quincy clay-gatherers, (d) Horse dump-carts and dirt wagons, with sectional slat bottoms.

Taking them up in turn:

Wheelbarrows.—The extent to which this most expensive and uneconomical mode of transporting materials still prevails in clay works is surprising. It is a common thing, in fact the usual thing, even in brick plants which use from three to five times as much clay as roofing tile plants, to find the clay undergoing one handling by wheelbarrow. The expense of overhead trestles, chutes, elevator storage-bins, or other means of using gravity or power to avoid hand labor has seemed too great in hundreds of plants where the daily labor bill for doing this work runs into large sums. It is not uncommon to find even two and in some cases three separate handlings of materials before they reach the grinding machinery.

It is probably allowable and proper, with only a tonnage of 50 or 60 per day, to use wheelbarrows *once*, at the clay-pit with a short haul, measured in a few feet or yards. But it is bad management when a wheelbarrow trip is extended to a distance of a hundred feet, and it is bad engineering when clay once lifted by man-power on a shovel has to be lifted by man-power again, prior to grinding.

Scrapers, Common and Wheeled.—The effective radius of action of a common scraper, carrying ⅜ to ½ of a cubic yard when heaped, is not more than a hundred yards. A travel exceeding that amount is costing more than is economical, for the number of trips per day is limited and a team is slow and cumbrous in turning and maneuvering for a load or for the dump and not rapid when in actual transit between terminals. The large wheeled-scrapers, whose capacity is from ¾ to 1¼ cubic yards, are much more effective and may properly be made to travel even up to 200 or 300 yards, though of course the shorter the travel the more economical they are. When once the clay is in a scraper of any type, it should never be shoveled after that time—gravity or power apparatus should always be provided for its reception and future handling.

Quincy Clay-gatherers.—These machines, from the standpoint of transportation, are about like the wheeled-scrapers. Their capacity is no larger, and their effective radius of action is therefore small. If worked over large fields, their capacity per day is quite limited. It is better to use the gatherers to do their specialized work of loading

and gathering, and to provide dumping stations in the fields, from which the clay can be loaded by gravity and trasported more quickly and more cheaply by wagons or cars.

Horse Dump-carts and Dirt Wagons.—A horse-drawn vehicle capable of hauling loads of considerable size, such as from 1½ cubic yards up to 3 cubic yards, can be economically used for transporting clays considerable distances. Instances of such transportation over mountain roads for distances of 10 or 15 miles are on record, but the cost of the clay of course was rendered abnormal and made a heavy tax on the company using it. Instances of a haul of 2½ to 3 miles, with a change of level of 300 to 400 feet, are on record for plants which have operated thus for 20 years, with considerable daily tonnage of brick and sewer pipe, but here also the cost, while not prohibitive, was high, and was a handicap in times of close markets. Hauling a wagon-load a mile is quite within reason, and permits the making of 10 or 12 loads per day.

In the fourteen roofing tile plants studied, five were using wagons or carts for transporting their clays. Two of them were located well within the limits of cities of a considerable size, so that other haulage, unless it should have been by tram-road, was out of the question. At the Alfred, N. Y., plant of the Ludowici-Celadon Company, the distance and route to be traveled would have made a tram-car system of hauling and maintenance very expensive, the distance being something over a mile, and unless a right of way could have been obtained along the public thoroughfare, it would have been necessary to have purchased a right of way through expensive village lots for nearly a mile and a half. In such a case, the wagon was probably the last resort.

In the case of the Huntington Roofing Tile Company, Huntington, W. Va., it was found that they were drawing their supply of shale from two banks, which are in different directions, distances and elevations from the plant. Their No. 1 bank, which is possibly three hundred yards from the pan shed, could be reached easily by a tram-car line, but bank No. 2 would be rather difficult to reach by car. Their use of wagon haulage at each bank is, therefore, probably justifiable, in that it permits them to keep a uniform mixture of their two shales, by hauling the desired quantity from each.

At the plant of the Alfred Clay Company, Alfred Station, N.Y., the shale was being hauled by wagon from a bank on the opposite side of a ravine, across from the plant. The plant being at a somewhat higher level than the shale-pit, it would seem that an inclined tramway could have been installed here very nicely and the shale handled at materially less cost. At present the material has to be hauled up a long winding hill, in very laborious manner. In general, it seems, then, that teaming is a commercially possible method of transporting for short hauls of a mile or less, but that it can scarcely be considered cheap for

distances of over a few hundred yards. Its use in many cases, like two that have been cited, is due to local conditions which rule out the use of mechanical power.

Tram-cars, Pushed by Hand or Horse.—The advantage of the use of cars is the great reduction in traction and the therefore greater speed and lower use of power, or what amounts to the same thing, the larger amounts which comparatively feeble power can transport. Also, cars permit of easy and varied modes of automatic discharge, adjusted in each case to the track systems or bins or chutes leading to the pans. The capacity of cars usually runs from one to two and one-half cubic yards.

The only illustration of the use of the hand pushed cars met was at the Detroit Roofing Tile Co., where cars were used to bring the clay from the margins of the bank to a central dumping point, from which a conveyor took the clay into the plant. The distance to be traveled was small.

Tram-cars, Transported by Mechanical Power.—In this group, we find the largest number of installations in clay works in general, and a considerable proportion among the roofing tile works. The modes of applying mechanical power are various, such as (1) cable-roads, lowering the clay down hill, or hauling it up hill or horizontally with tail-rope haulage; (2) steam locomotives or dinkeys; (3) electric motor haulage.

At the Western Roofing Tile Co., Coffeyville, Kan., where the material must be elevated from a pit below the plant level, an inclined track is used, with an end dump car.

Fig. 52—Shale Bank and Car of the Western Roofing Tile Company, Coffeyville, Kansas.

The above cut shows the car, loaded, ready to be hauled up the incline by an ordinary winding drum with friction power and friction brake.

It will be noticed that this car is provided with an extra set of wheels placed on the main rear axle, which was made longer to accommodate them; these wheels do not run on the hauling track, but when the car reaches the point where it is desired to dump the load, the main track at this point becomes horizontal, and an extra set of rails are placed just outside of the regular track, where these outer rear wheels engage on them and come into action. These outside rails continue up at the previous angle of the main track, so as the car moves forward the front end moves in on a level track, while the rear end is raised higher and higher until the load slides out of the front end of the car by gravity. This style of self-dumping car costs very little extra, gives very little trouble by accidents or repairs, and can be commended as an ingenious and useful tool. It should be said that this company built its own cars.

The United States Roofing Tile Co., of Parkersburg, W. Va., uses another style of car, a side dump, made by E. M. Freese & Co., of Galion, Ohio. The conditions at this plant are different in that the shale is in the neighborhood of a hundred feet above the level of the plant, so that instead of using a cable and power winding drum to elevate the cars, a cable and friction drum without power is used to lower them down the incline.

In this instance, advantage has been taken of the power developed by the loaded car going down the incline to haul the empty car up. After the first installation has been made, this system is self-supporting; that is, no outside power is supplied to operate it.

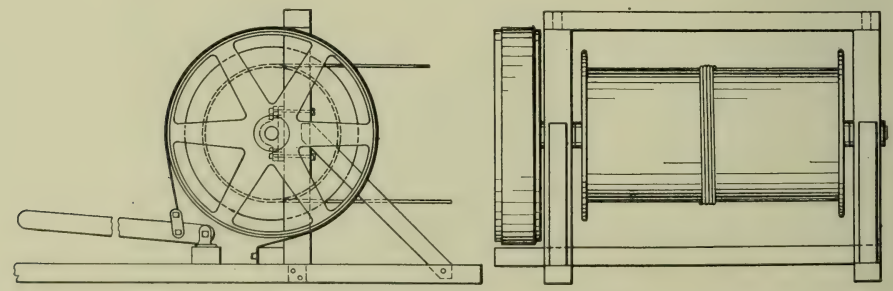


Fig. 53—Home-made Winding Drum, in Use at United States Roofing Tile Co.

It will be noted that this drum is a very simple affair; with the exception of the iron work, it was built by the company's carpenter. The staves of the drum are of oak, about three inches by five inches, and five feet long. The brake wheel is an old band wheel, and the brake band itself was a piece of kiln band-iron, seven inches wide by three sixteenths of an inch thick. It will be noted from the illustration that there are only four laps of the cable about the drum. In fact, two would have been sufficient.

The object in having the drum so long is to provide travel space for the cable laps. When a car is to be let down the incline, the cable laps are either to the right or left hand flange. As the drum revolves, the cable travels across the face, reaching the opposite side as the car reaches the foot of the incline.

Another feature of this equipment is the three rail tramway, instead of the usual complete double track. In order to save on the construction, which was high on account of costly trestling, the company made the trestle work narrow, and a three rail track system was constructed. At the passing point, or half-way down the incline, it was necessary of course to put in a double track or switch for a distance of thirty feet to allow the cars to pass. At this passing point the rails are so cut and laid that no attention has to be given to make the cars take the proper route.

The method of operation is as follows: In the beginning the first car up the incline had to be taken up by block and tackle; when loaded it was run out on the main track in front of the drum where it was hooked onto one end of the three-fourths inch steel cable. At the lower end of the incline an empty car was hooked onto the other end of the cable. The full car was then started over the brink and proceeded on down the hill, its speed being controlled by the friction band, and the up car passed it at the switch. As the loaded car reached the bottom, its impetus carried it on into the storage shed, and the empty car was pulled over the brink of the incline and out on to the level of the pit floor. Both cars were now uncoupled, the loaded one moved by hand through the shed to the desired point for dumping, a catch-pin was removed, and the load, which was purposely a little overbalanced on the dumping side, immediately caused the car to tip to an angle such that the charge slid out. The car was then righted and run back to the loose end of the cable and hooked on, ready for the up trip. At the upper end of the line, the second car was loaded and made ready to lower. This system requires two men, one at either end, besides the loaders.

Where the elevation of the shale or clay bank is such that this system can be used, it is to be recommended on account of its simplicity and the low cost of operation.

At the New Lexington plant of the Ludowici-Celadon Co., the cars in use were made by the Star Manufacturing Co., of New Lexington. The car is a heavy wooden one, strongly ironed, and for dumping is provided with two hinged wings which meet in the center when the car is closed, and which swing down vertical when the bolt is withdrawn, leaving the bottom of the car wide open for the full width and two-thirds of its length.

At the above plant and at the Parkersburg, W. Va., plant, also, the shale pit is at a somewhat higher level than the factory, so that the

material must come down an incline. The grade, though, in this case is rather low, so that the cars, which are provided with good brakes, are loaded and started down the incline without use of any cable. A man rides the car down, controlling its speed by the brakes to suit himself, it only being necessary to apply a very little pressure to stop the car at any point.

At the foot of the incline, the car enters the stock shed, and is allowed to run on into the shed to the desired point. Here a latch is released, and the two hinged wings forming the bottom of the car swing open, allowing the load to drop through between the track rails to the floor of the storage shed some twenty feet below. The bottom wings are then pulled back into position by a chain winding up on a shaft and locked by a ratchet. The car is then pushed out to the foot of the incline, where it is hauled up the incline to the bank by a horse. This horse has been trained to follow the load down at his leisure, in time to pull up the empty car.

Fig. 54—Shale Bank of the Ludowici-Celadon Co., New Lexington, Ohio.

At this plant the short distance of the material from the plant makes it possible and economical to move the shale from the bank to the shed in the above manner, and the low grade would make operation with a friction drum difficult. This plant is unquestionably handling as much or more raw material than any other roofing tile plant in the country. This plant affords one of the best examples of a proper provision of clay under cover in storage for use in bad weather. They

have a shed 60 feet wide by 150 feet long, with the track supported on the bottom chords of the roof trusses, about 20 feet from the floor. This whole immense space once filled would enable them to work for weeks without any other supply. A conveyor is used to move the material from the shed to the dry pans.

The Murray Roofing Tile Company, of Cloverport, Ky., as mentioned before, works a mine to win its shale. The entrance to the mine is about 100 yards from the plant, and at a level a few feet higher than that of the plant. In order to get storage room, the track has been carried into the storage shed at a slightly higher level than the mine entrance, so that the cars run back to the mine by gravity after dumping. (See Figure 50.) To bring the cars from the mine a simple winding drum is used. This drum is located at the inner end of the stock shed, and is belt-driven.

At the Ludowici, Ga., plant of the Ludowici-Celadon Company, the horizontal track system a mile or more long from the clay pits to the works is used, and the cars are hauled over in trams by mules. The face of the pit is kept vertical, so that the cars can be run close up parallel with the working face. The workmen are stationed at various intervals and levels, the bank being worked in steps, of single spadings deep, one man working on each step. (See Figure 42.)

Railroad Cars.—At two plants, where the materials and plants were widely separated from each other, viz., The Mound City Roofing Tile Company, of St. Louis, and the Cincinnati Roofing Tile and Terra Cotta Company, of Cincinnati, Ohio, clays are shipped in full-sized railroad cars. At the former plant the shale is shipped a distance of about 25 miles, while at the latter the material is shipped about 100 miles.

After the cars of material reach the plant they are for the greater part of the time unloaded by shoveling into the dry pan direct, but at other times the clay is carried into large storage sheds for the winter use. When the sheds fill up to a point where the men can no longer put in more material by shoveling from the car, wheelbarrows and runways are resorted to in order to get the clay farther back into the shed.

This method of handling the raw material is quite costly, for it must be wheeled for a third time when needed for use. It would seem that a short portable conveyor reaching from the side of the car back into the shed as far as desired could be easily arranged. It would be necessary, of course, to have a countershaft extending the full length of the shed, with driving pulleys at regular intervals where the conveyor could be attached. When one part of the shed was filled it would only be necessary to move the conveyor on to the next section.

When it became necessary to draw on the reserve stock of material, it would again seem advisable to use a conveyor extending laterally in the shed, so that a man stationed at any section of the storage shed

could shovel direct onto the conveyor, which in turn would deliver the clay to the dry pan for grinding. Whenever the distance exceeds a few yards, one man could easily move as much material in a given time by means of a conveyor as three men could move with wheelbarrows.

The Conveyor System.—A little illustration of the use of the conveyor other than the suggested case just mentioned is that of the Detroit Roofing Tile Co., of Detroit, Mich. Their conveyor reaches from the grinding room out into the clay pit, a matter of fifty or more yards distance. This conveyor is merely an endless rubber or cotton belt, about fifteen inches wide, carried on rollers at intervals of a foot or so apart. The power to drive the belt is supplied at the discharge end by a geared friction wheel and tightener.

At first it was possible to shovel the clay direct from the bank onto the belt, but as the pit enlarged it was necessary to install two hand push cars, shown in the illustration. By observing this figure, No. 56, it will be seen that the clay is dug in benches, or spadings, each car being loaded with a definite number of shovelfuls from each bench, thus bringing every level of the bank equally from top to bottom. When a car is thus loaded, it is pushed to the conveyor by hand, and there unloaded by hand. There are limits in the matter of elevation to which this system of clay handling could be employed, but by means of cleats or flites fastened to the belt the material could be carried down or up a rather steep angle—at least 25 degrees. The development of conveyor systems, with enormous carrying capacity and with adjustable dumping points, has reached an advanced stage of development in many lines of industry. The limitation which prevents their wider use in roofing tile manufacture is the small tonnage they are called on to handle and the relatively great expense for installation and up-keep. However, simple, straightaway belts of moderate capacity are no longer costly, and they are very simple and efficient in use.

THE GRINDING OF ROOFING TILE CLAYS.

The purposes in view in the grinding of clays preliminary to manufacture by the plastic, or stiff mud, process are generally twofold:

First—To break up any impurities or obnoxious minerals which may happen to be present in coarse form, and disseminate them uniformly through the mass—in other words, to homogenize the clay so that any one cubic inch of it will have the same physical and chemical properties as any other cubic inch. It often happens that the minerals composing a clay or shale are not obnoxious if properly distributed, but if left in coarse lumps they would be classed as impurities—quartz or sand-rock, for instance, which is likely to be a really desirable addition to the clay if it can be properly distributed. It also generally happens that other minerals commonly found in clays, such as limestone or

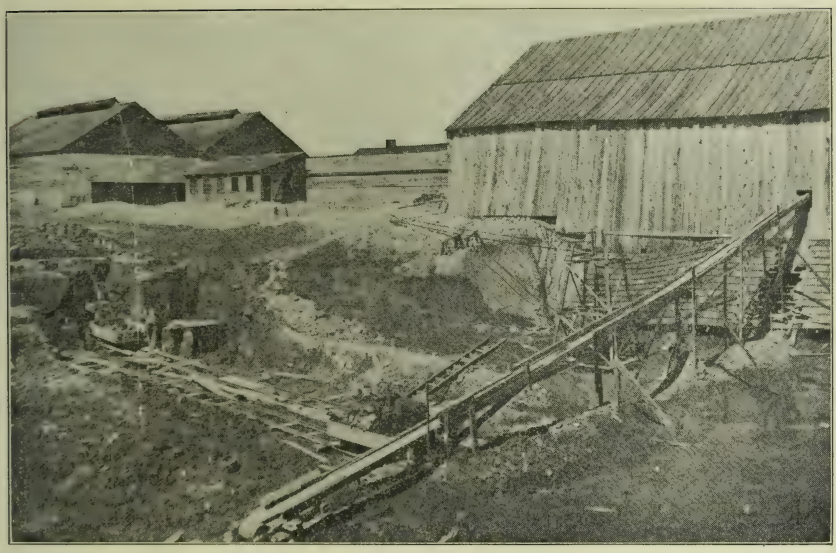


Fig. 55—Conveyor at Detroit Roofing Tile Co.,

Fig. 56—Clay Pit at Detroit Roofing Tile Company.

iron ore, are regarded as impurities under practically all conditions, either before or after grinding, but by fine grinding and more even distribution their evil influence is much reduced.

Second—To create plasticity in clays which have been so long stored in rock form in the earth's crust that they have lost this property to a large extent, or rather, it lies dormant and undeveloped. The grinding makes it possible to apply the softening power of water on an enormous surface area at once, and also to create a plastic paste out of the finer portions of almost any rock powder. There are clays so hard and stony that no great or sufficient plasticity can be developed, even after persistent grinding with water in powerful machinery, but these are exceptional.

These two purposes are most commonly both represented in the grinding treatment of a given clay, but in some cases only one purpose may be in view. In general, in soft, plastic, glacial or alluvial clays there is no need of grinding to develop plasticity—in fact, they more often need some anti-plastic body, like sand, to cut down the excess of plasticity. Grinding, in such clays, is therefore chiefly for the dissemination of the harmful impurities, and in some few machines their removal. A grinding treatment of such clays is often very perfunctory, and sometimes omitted entirely. In many shale clays the homogeneity of the material itself is very good, and no impurities of importance exist, and here the grinding is wholly with a view to obtain a plastic paste.

Grinding treatments for the plastic process of manufacture, whatever object, are divisible into two groups—wet grinding and dry grinding. It will be understood that the following remarks are not intended to apply to the slip or washing process of preparation for pottery clays, or to the dry press process, which finds little if any use as yet in roofing tile manufacture. In general, wet grinding is practiced where defective plasticity is found, as it is very much more powerful in developing the latent plasticity of a clay than any other treatment. At the same time, the ability to size the grains and secure the crushing of all of the coarse impurities, and thus secure high homogeneity, is largely lost in wet grinding. Hence this threatment is usually applied to the harder shale clays and fire clays, and when applied to very plastic clays the grinding is very short-lived and imperfect.

In general, dry grinding is practiced where the material is unhomogeneous naturally, and where its lack of homogeneity would be severely felt in the product if steps were not taken to overcome it. It is followed ordinarily by screening, which establishes the limits of the size of any particles in the clay, and is therefore the guarantee of homogeneity. The screened powder is then to be converted to a plastic paste by a subsequent process. Thus it is seen that the dry grinding and wet grinding operations are really more than alternative routes to the same

goal. To a considerable extent they produce different results and are applicable to different clays.

The determination of which treatment should be given in any individual case is a matter of judgment with the operator. The wet treatment is slower, more costly, and has less control of the homogeneity of the product, but produces by far the best plasticity, and can be used where plasticity can be gotten in no other way. In general, any clay *can* be treated by this process, but it is rather uncommon to use it except where necessary on account of the reasons given above.

The dry treatment is faster, cheaper, produces a more homogeneous paste, but of deficient plasticity. It can be used with clays of good and moderate plasticity, but not very well with those of low plasticity. Wherever it can be used it is very likely to be selected for the reasons above.

With these preliminary statements, setting forth the theory of the grinding process, the different modes of doing the work will be considered. As in the case of winning, and in short throughout this report, no attempt will be made to discuss all possible modes of treatment. Those actually found in use in roofing tile plants will form the basis, with such suggestions of other processes as may seem worth while.

Grinding With Rolls.—The roll is one of the simplest and oldest forms of grinding machines. Essentially it consists of two cylinders or cones, whose surfaces are in close contact or held closely parallel to each other. Their axes must be in the same plane, and in the case of cylindrical rolls they are parallel, but in the conical rolls the axes are inclined to each other by an amount proportional to the taper of the cones. By revolving these rapidly toward each other, any object caught between them tends to be nipped and carried through. If it is not too large and too hard, it will be crushed in passing; if it is too large it will not be nipped, and will simply roll around on the surface of the rolls without effect. If it is small enough to be nipped, but too hard to be crushed, one of three things will happen—the rolls will stall and stop, or they will spread apart to let the hard particle through, or they will break. In practice, they are held to each other by heavy springs, which permit them to spread momentarily in passing an exceptionally hard piece, rather than accept the other two alternatives of stopping or breaking.

Rolls are designed for two different ends: First, as a wet grinding machine for crushing stony, plastic clays, and for rejecting the rocks or hard portions which are too large to fall within the angle of nip; second, as a dry grinding tool for pulverizing large quantities of materials of nearly uniform size of grains. The commonest use of rolls in this way is as a tailings grinder, to finish the grinding of small particles which are partly reduced, but not enough so to pass the screens.

Wet Grinding Rolls.—These constitute the most simple method found in use for crushing soft plastic clays. Two roofing tile plants were using this method: The Detroit Roofing Tile Co., at Detroit, Mich., and the Dixie plant of the Ludowici-Celadon Co., at Ludowici, Ga. The clay of the former company as stated before is a fine grained blue and gray, alluvial clay, soft enough to be won by spading, and hence very easy to grind, and so plastic as to be very difficult to grind in a strictly dry grinding machine, like a dry pan. The clay coming from the pit by conveyor feeds directly into a pair of smooth rolls, made by the Horton Manufacturing Co., of Painesville, Ohio. These rolls are differential, one being a small roll driven at high speed, and the other a larger and lower speed roll. They are set up within a small fraction of an inch of each other. The small roll, about nine or ten inches in diameter by two feet long, runs at approximately five hundred revolutions per minute, while the large roll, about eighteen inches in diameter, makes but one hundred and fifty revolutions per minute. The peripheral speed of these two rolls is quite different, so that when clay is fed into the machine, it not only squeezes and crushes it, but also shreds and tears it apart as well. The lumps or pebbles are caught up and crushed very fine, the size depending of course on the opening between the rolls. This machine is able to take clay either dry or wet and carry it through. Ordinarily as the clay comes from the bank it is of suitable water content for stiff mud work, but if too dry, a little water is supplied immediately after passing the rolls. As the clay drops down from the rolls it falls directly into an open topped pug mill, eight feet long, also made by the Horton Manufacturing Co. The clay slowly works its way through the pug mill, and drops onto a platform from whence it is picked up by a man who tosses or slams it into storage or aging bins, being very careful to get the clay well packed in the bins or pits. It is here allowed to stand about three days, enabling the water content, if unequally divided, to equalize itself through the mass by diffusion. A more uniform product is thus obtained.

In the Dixie plant at Ludowici, Ga., as was noted under the heading of winning, they are working a very fine grained plastic clay, which rests upon a water-bearing sand; in fact, some of the clay is at times dug out of water (Fig. 42). It therefore usually comes to the plant in a wet, semi-plastic condition. It should be mentioned here that for reasons discussed later, a small proportion of a very sandy shale, previously ground and screened, is added to each car of the plastic clay as it comes from the field. This shale is, of course, in a dry, dusty condition, very different from that of the clay.

The car, with its double charge, proceeds up an inclined trestle to a hopper, where it is dumped. This hopper stands immediately over a pair of smooth rolls specially made for the company. These rolls are very large, and run at a relatively slow speed. They are two feet long

and thirty inches in diameter. The rolls being of the same size and running at the same speed, the clay in passing through them is crushed or squeezed, rather than shredded or torn apart. After passing through the rolls, the clay drops into a combined pug mill and auger machine made by J. D. Fate & Co., of Plymouth, Ohio.

This machine is used as a closed top pug mill, rather than a true auger machine, as it does not turn out a finished product. As the clay issues from the end of this mill it is taken by men and slammed down hard into soaking or aging bins, where it remains about one week. This allows the excess water in the field clay to come in contact with every particle of the dry ground shale that has been added to it.

In this plant is illustrated a treatment admirably suited to their material. The homogeneous quality of the clay is such that actual grinding or reduction of size of grain is not needed. What is needed is a thorough mixing of the plastic clay so that the layers representing different spadings shall be wholly obliterated and a new ingredient entirely foreign to the clay itself shall be uniformly disposed through it.

In their mechanical treatment, the crushing effect of the rolls is followed by the combined work of a double shaft pug mill and the compressing effect of an auger machine, which not only thoroughly mix the ingredients, but compress them into a dense mass, excluding the bulk of the air, and bringing the particles of clay substance into close contact.

Dry Grinding and Stone Separating Rolls.—Owing to the wide distribution of excellent alluvial clays and shales in the United States, very few persons will attempt to use a glacial clay for any but the commonest kinds of material. Only one plant was found using a glacial clay for roofing tile manufacture, viz., the Chicago Heights plant of the Ludowici-Celadon Company. Their clay is an average sample of the glacial clays which characterize the Chicago district. These clays are still plastic as they are taken from the pit. They are fine grained in the main, but very badly mixed with coarse and fine glacial pebbles of all sorts. Of glacial clays in general, owing to their origin in ice sheets moving across the earth's surface, it is to be expected that they will be heterogeneous in nature, and composed of a mixture of what they have passed over, viz., boulders, gravel, sand, rock-dust and clay substance. The stones may vary in size from boulders of enormous size down to the point where they lose their identity, and are called gravel. The ingredients may not only vary widely in size, but in proportions also, and they may also have a wide range in composition, i. e., different minerals and different amounts. Thus the man who attempts to work a glacial till is not only confronted with the working of a very impure clay, but at the same time a very variable one.

The Ludowici Company has been working a material of such characteristics since about 1893. They have not only succeeded, but have

proved that without question good roofing tiles can be made from this and similar heterogeneous clays elsewhere. This company, apart from the original error in judgment, in establishing such a plant on such a clay, has faced these most trying conditions with fine determination, and has unquestionably brought more real engineering science into use in surmounting its difficulties than any other roofing tile plant in this country. It is not meant that other plants could not have done the same, but the nature of their material has mercifully not required it.

The problem of successfully working a glacial clay begins in the clay-pit. By referring back to the discussion on winning, it will be seen that this company is using the Quincy clay-gatherer, which is undoubtedly the finest tool in use for the careful averaging of the clay as it is taken in the field. The clay is dumped by the clay-gatherers in a stock house or storage shed of immense proportions, holding clay enough for several months' operation in the winter, when the bank is too wet for possible winning. Through this stock-shed, a central conveyor-belt runs, which can be loaded by shoveling from any point in the shed.

This conveyor-belt delivers at one end of the shed to the first machine—a pair of conical, dry-crushing rolls, smooth surface, set one inch apart, and running at 75 revolutions per minute. These rolls crush the lumps of clay and smaller pebbles; any stones that are considerably larger than the opening, i. e., too big for the angle of nip, gradually work their way to the large end of the cones, where they fall out into a wheelbarrow, to be removed. The use of these rolls is chiefly for the sake of their qualities as stone separators, but the next step in the process would hardly be successful if the clay had not been first crushed and shredded.

In a day's run of ten hours, nearly ninety tons of clay pass through this small pair of rolls. In size they are about two feet long by twelve inches at the large end, and seven inches at the small.

It will be understood that the gravel stones smaller than the space between the rolls have passed on through untouched. In this condition the clay-mixture could not be used for roofing tiles or any product. Finer grinding must be resorted to; in fact, it must be extremely fine in order to prevent the lime-pebbles from pitting or "popping out" in the burned tiles. No instance was observed in the roofing tile plants of the country of the use of the dry-crushing rolls for very fine sizes, i. e., tailings crushers, but such a use is common in other branches of the industry. No instrument is more efficient or does more work for the power used, in crushing an even-sized granular material than rolls.

Grinding With Dry-pans.—This machine is so well known in all branches of clay manufacture that no space will be used in describing its construction. It is in use in all countries where clay working has progressed beyond the rudimentary stage. No other tool wholly takes

its place as a rough and ready grinding machine, in which the material comes to it in widely varying sizes, from large lumps of several hundred-weights down to dust; in widely varying hardness, from "nigger-head" boulders in glacial clays and carbonate of iron concretions in shales down to soft crumbly earth; in widely varying degrees of plasticity, from sticky paste after a rain up to bone-dry materials returned from the driers for reworking; and in rates of feeding, varying from overloads of 300 or 400 per cent. down to frequent periods when the machine is running empty. All these irregularities occur in any works, and on every dry-pan. No machine that cannot give a good account of itself under such conditions will ever displace the dry-pan as a clay-grinder's main reliance.

There are a number of different designs on the market, varying in various more or less important details. There are over-head driven pans, versus under-geared pans. The latter are common in ironworks for wet-grinding iron ore for puddlers' "fix," but they are not common in clay works for either wet or dry use. The advantages claimed are the low frames, the accessibility of the pan itself, and the housing of the gears under the pan free from dust of the shop. On the first and second points, no argument can be raised, but the gears underneath are very doubtfully better placed as far as saving the gears themselves from wear and tear is concerned.

There are wooden framed versus cast-iron framed, and the latter versus the structural-steel framed pans. The former are fast passing from use and the latter are coming in. The vast majority of pans now in use have cast-iron frames. The wear and tear on cast frames is very severe, and breakage is not uncommon if the bolts are allowed to work loose.

There are pans with separately suspended mullers and those with yoked mullers, i. e., both on the same shaft. The ends of the shafts are held in position by side guides, but are free to move up and down to accommodate the various sized lumps of material passing beneath the mullers.

With a continuous shaft, i. e., the yoke pattern, the lifting of one muller throws the opposite one into a position where it is running on the outer edge of its face, hence doing very little work, while in the case of the independent mullers each works without interference from its neighbor.

The propelling force of the mullers is derived through their frictional contact with the floor of the revolving pan, one muller moving in one direction and the other in the opposite.

It is claimed by the manufacturers of yoke-muller pans that they can get a larger tonnage per day through their pan than the other type, their contention being that with both mullers on the same shaft, they obtain more weight to crush the material in hand, and can hence grind more in a given time. This claim can hardly be substantiated, for it

is the repeated blows of the mullers that break down the hardest material, and not their mere weight. Their combined weight can never be concentrated on one end in any case. It may perhaps be conceded that the yoked muller-pans runs smoother and with less jumping than the independent muller-pan and may possibly, by reason of this, wear longer, but as to their giving an extra output it will not be agreed to without more figures from some uninterested source. Either style of pan, though, proves successful in a roofing tile plant, because here quality of work is considered more largely than quantity. In no case are the pans likely to be run to their full capacity, for the tonnage of clay to be ground is relatively small and the problem is quite different and much easier to meet than in brick manufacture, where output is much more important.

Pans are also usually constructed with scrapers underneath, which revolve with the pan floor, dragging the c ay ahead to one point of delivery on the circumference, but in some instances large concrete brick or stone foundations are built with sufficient depth to permit gravity feed of the powdered clay to the point of delivery outside of the base. This method reduces the friction of the pan considerably, and seems destined to find general acceptance wherever the local situation permits the necessary depth of pit.

Pans are also arranged with direct drive, from coupled engine shafts (rare); direct drive with geared electric motors, a new form still rare, but likely to become much used; and belt driven, comprising the vast majority. The belts are arranged to drive pulleys placed inside the main bearings of the top frame, or over hanging pulleys, or pulleys with separate outboard bearing. The belt drive, with either self-contained or outboard bearing, makes a perfectly safe and satisfactory drive and is likely to persist in general use as the most generally convenient.

Besides these variations in the larger questions of design, there are innumerable smaller ones, such as chilled cast iron muller tires vs. special chrome or manganese steel tires; friction clutch vs. tooth clutch vs. fast and loose pulleys for starting and stopping; fixed vs. adjustable scrapers; and the kind of step or bottom bearing to carry the weight of the vertical shaft.

The step is one of the most essential features about a dry pan. In the ordinary pan, the weight of the pan bed, vertical shaft and gear wheel, the combined weight of the two mullers and their shafts as well as the eight hundred (800) to sixteen hundred (1,600) pounds of clay in the pan is carried upon this small bearing.

This means that a load of five or ten tons is carried upon a bearing not as a rule exceeding five inches in diameter. This bearing tends to heat very easily and unless proper oiling facilities are provided, it will prove very short lived. Ball-bearing steps have been brought out

from time to time, but they have made no impression on the market. The principal thing is to secure positive and copious lubrication. Nearly any step, if of adequate size, will stand well if it is kept thoroughly lubricated and clay dust and grit are kept out of it.

In selecting a pan one should try to secure one that is strongly built—not only strongly built but well built. By this is meant one that has every joint and bearing *planed* and *fitted*, every bolt hole *drilled* and machined bolts that properly fill the holes. There is not another machine about a clay plant that has to stand the rough usage that the pan is expected to endure.

Unless the pan is built as above stated, it will only be a matter of a short time until it will be creaking at every joint, consuming a great amount of extra power, and in fact pounding itself to pieces.

Pans of the other type, with cored bolt holes, can be seen in some of the roofing tile plants. In one instance a pan was found so poorly constructed that there were numerous bolt holes so out of line that bolts could not be put in at all, or had to be driven in. There is, however, a marked change in the last few years toward better clay-working machinery, and the machine manufacturers should be given credit for what they have done and proper encouragement to do still better.

As before stated the step or bottom bearing is very important. Select the machine having a large and easily accessible step, one that runs in oil and that can be opened easily for inspection.

The two most neglected points about a clay plant are: first, the dry pan step, and second, the elevator boot. The location of both of these parts is so inaccessible and so dirty, that the tendency to neglect them is strong. Unless the pan has a step that can be easily reached and easily taken apart, it is certain to be neglected. The pan tender will ordinarily not take the trouble and undergo the discomfort necessary to inspect the step, until forced to do so by the evident signs of distress from that locality.

It is entirely impossible for any one to say that all the virtues are to be found in any single design. There is no *best* pan in the sense of one filling all situations best. Of those actually found in use in the roofing tile plants of the country the following makes were recorded.

American Clay Machinery Company	7
Frost Manufacturing Company	3
C. W. Raymond Company	2
Bonnot Company	1
	13

Grinding by Disintegrators.—At the plant of the National Roofing Tile Co., Lima, Ohio, a method of grinding is used that is not to be found in any other roofing tile plant in this country, though the method is common in other branches of the industry.

This company is using a pulverizer manufactured by Williams Patent Crusher & Pulverizer Co., St. Louis, Mo.

The machine consists of a horizontal shaft to which are keyed a series of discs, through the circumference of which bars are run, and upon the latter are hung swinging hammers, which, by centrifugal force, fly straight outward on a line from the center of the shaft when the machine is rotated at high speed. The hammers swinging outward strike a very powerful blow, but the hammer is not rigid or inflexible, being held out merely by the centrifugal force and being free to bend back to the center whenever it comes in contact with a body heavy enough to overcome the centrifugal force. This acts as an ingenious protection against breakage by foreign material, like picks, bolts, shovels and the like falling into the hopper. The machine is run at a very high rate of speed, so that the material to be pulverized is subjected to many thousand blows per minute. The clay, being subjected to such severe treatment as this, is completely broken up before leaving the machine. It will be noted from the cut that the clay in the case of the National Company is elevated by the cup elevator, on the left side of the machine, to a point where it is fed into the hopper. Upon passing out it is again caught by a second elevator, shown on the right side of disintegrator. This elevator carries the clay to a sixteen mesh screen on the third floor of the building. That part of the clay which is fine enough to pass the screen falls into a storage bin while the coarse material is returned to the disintegrator by the chute shown in cut.

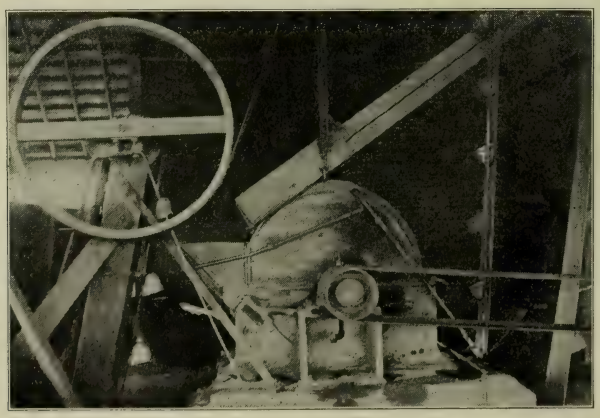


Fig. 57—Pulverizer or Disintegrator at Works of National Roofing Tile Company, Lima, Ohio.

It is found advisable to bring the clay to the disintegrator as dry as possible, and even then provision is made to steam heat the jacket of the mill in order to prevent the clay from packing or caking on it.

For clays of a dry, compact, fairly hard nature, this style of machine will unquestionably break up the massive lumps and reduce the

whole to a moderately fine powder at a good rate, varying with the size of machine, horse power used, and rate of feed. If the clay be a fat, sticky one, as in the case of the clay at Ludowici, Ga., it would prove impossible to work it through a disintegrator. Even moderate dampness must be guarded against as shown by the use of the steam-heated jackets in this style of machine.

The relative performance of a disintegrator versus a dry pan, which is the only other machine with which a comparison is at all apt, is still a matter requiring proof. Makers of both machines claim all the advantages for each. It is also certain that a big disintegrator, given the power and speed, will grind, at a furious rate, anything in the clay line, excepting wet clay. But any intelligent comparison must show the relative power consumption on the same materials, and the output per day per horse power used, and also the relative repair bills for a year or so. Such figures are not available. The use of the disintegrator has been known to clay workers for twenty years or more, but has made comparatively little headway in displacing the dry pan, while for harder and more brittle materials, less liable to pack or cake in the machine, the disintegrator is finding a very great market.

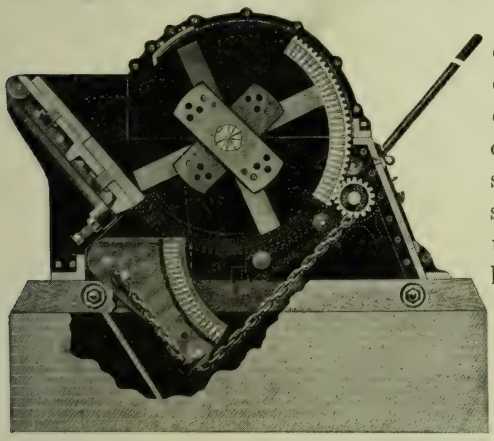


Fig. 58—Sectional View of Disintegrator

Wet Grinding. — The preceding types of grinding machines are designed to operate on clays of various stages of dryness, from the cheesy consistency, as spaded out of a swampy pit at Ludowici, Ga., up to the carefully predried and heated clay at Chicago Heights, Ill. In all these cases grinding is followed by tempering, a second operation for the development of plasticity, before going to the ware-forming machines. There are two other processes of grinding in use which differ from the preceding in the fact that grinding and tempering go on jointly in one and the same machine, which delivers the plastic paste direct to the forming machinery.

The Chaser —This machine, now rarely seen, was originated, or at least most largely used, in the Akron district of Ohio. It was employed in the sewer-pipe and stoneware plants which have been very numerous there for forty or fifty years—in fact, for years these industries thought they could use no other device. From Akron as a center, the chaser mills were sent all over the country in the sewer-pipe and stoneware trades, and they may still be found occasionally, though few if any new ones are being installed. The Akron Vitrified Roofing Tile Company used this machine exclusively for the tempering process for all the

earlier period of their existence. They were preceded in this direction, however, by the Bennett Roofing Tile Company, of Baltimore, Md., now dismantled.

The clay used at the Bennett Company was a soft yellow alluvial material. Upon being hauled to the plant by wagon, it was stored in bins until needed, then being wheeled by hand to the chaser, which was made by Turner-Vaughn-Taylor Company, of Cuyahoga Falls, Ohio. The clay to the amount of 800 to 1,200 pounds was dumped into the pan of the mill, water added, the mill started, and the work of grinding carried on for from twenty to thirty minutes per charge. The mill was then stopped, the clay shoveled out, and packed in bins to age a little before being pressed into tiles.

The construction of the machine can be readily understood from the following illustration:

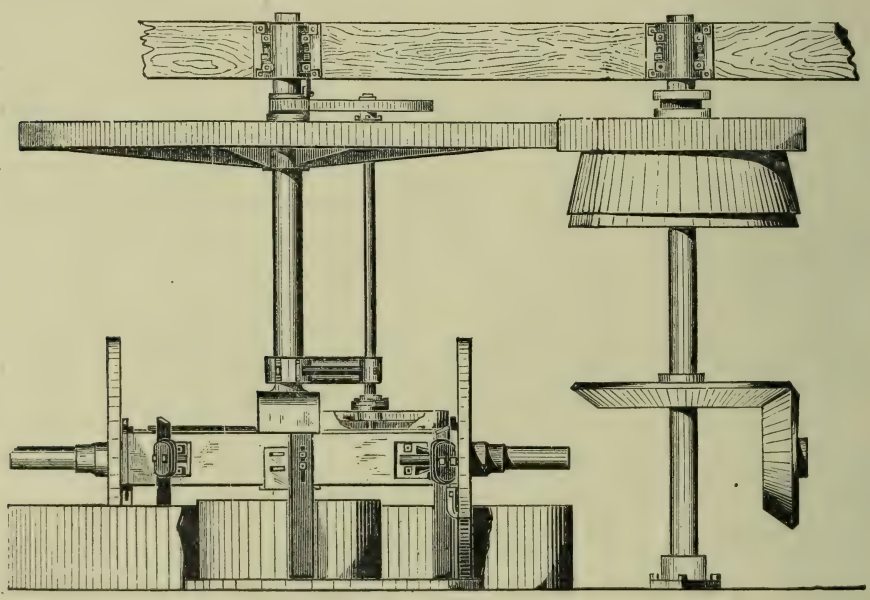


Fig. 59—Chaser Mill.

The machine differs from other pan grinders in the fact that the pan floor is solid, or stationary, while the grinding wheels run in circular or spiral tracks around the central vertical driving shaft; hence the name "chaser," for the wheels seem to be in endless pursuit of each other.

The action of the chaser cannot be considered efficient from the standpoint of power consumption, daily output of clay, labor required or homogeneity of product. It is slow, costly to operate, and not thorough. Nevertheless, it gives to its product, or at least its advocates so claim, a toughness and cohesion not attained by other forms of tempering appliances. Rarely will a person accustomed to the use of clay

from a chaser mill willingly accept clay from any other process as a fair equivalent. This idea is too universal among workmen, foremen and owners to make it likely to be wholly a prejudice. There is a foundation of truth, and the cause is to be sought in the peculiar variety of sizes of grains in the product. The principle of a dense structure requiring a variety of sized grains is known and recognized in cement work and mortar materials, and has been broached often in connection with the differences in strength and toughness of clays, and it is the probable cause of the peculiar tenacity of chaser-tempered clays. It will be at once understood that there is no screening or sizing process possible where wet grinding and tempering processes are employed, and the study of the product of a chaser shows a much wider variety of shapes and sizes of grains than do clays which have been screened dry. No matter how long the grinding is continued in this machine, some coarse particles will always dodge the narrow tread of the tempering wheels.

The Wet Pan.—The wet pan, as originally used, is simply a solid bottomed pan, of exactly similar variety of construction to that found in dry pans, into which raw clay is thrown in 800 to 1,200 pound charges, and ground and tempered in one operation and without prescreening or any final sizing of grains in the plastic paste. It is still used exactly in this way in the fire-brick industry, where charges of hard, flinty clays mixed with burnt "grog" are ground until enough plasticity is developed to permit hand molding of simple shapes. Often thirty to forty-five minutes are consumed in tempering a single charge.

This mode of operation, which justly entitles the wet pan to a place among grinding machines, is not employed at all in the roofing tile industry so far as known. The latter and common use of a wet pan is as a tempering machine, beginning with materials previously ground in a dry pan and screened to the requisite fineness for the product. It cannot be doubted that under these conditions the wet pan still acts as a grinding machine, and that tempering even for 2½ or 3 minutes, which is the usual time when screened clay is used, results in some increased fineness of grain. Nevertheless, the tempering or development of plasticity is the important feature, and the grinding is incidental (though more important than is generally conceived or admitted). For this reason, the further discussion of the machine will be deferred till the topic of tempering is reached.

Drying and Preheating of Clays Before Grinding.—The greatest obstacle in the preparation of clays by all-dry, semi-dry, or plastic processes, in short, by all processes except where the clay is reduced to a state of fluid suspension as in the "washing" process, is the constant tendency to clog up the machinery by reason of its strongly cohesive properties. These properties are essential—the foundation, in fact,

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of the clay's value over other minerals, but they make clay preparation difficult and inexact.

Rolls, of all grinding machinery, are best able to deal with a clay in the cheese-like plasticity found in nature. Dry pans can handle a limited amount of such clay if mixed with some dryer material, but the capacity of a pan falls off very rapidly with each increase of water, over five or six per cent., and at thirteen or fourteen per cent. the pans will not put through $\frac{1}{8}$ or $\frac{3}{16}$-inch screen plates more than twenty-five to thirty-three per cent. of their normal output. With actual plasticity, the dry pan becomes impossible. Disintegrators are even more susceptible to hindrance from moisture than dry pans.

After a clay has been through a pan or equivalent, and is in the form of a coarsely granular powder, the screening still remains difficult if moisture exceeding five or six per cent. is present. Caking on the screen and covering the holes, agglomerating and rolling along on the surface without passing through, sticking fast in the elevator cups and refusing to dump, choking up spouts and runways, etc., are the troubles incident to dry clay screening. Water is at the bottom of all these troubles and thoroughly dry clay grinds and screens as easily as could be desired.

These difficulties all increase directly in proportion to the fineness of the powder which is to be produced. In order to get clay fine enough to make a good homogeneous roofing tile body, especially if it contains lime or iron minerals in lumpy form originally, it is sometimes necessary to dry the clay in advance by some artificial treatment. Winning in good weather, airing before gathering, storing in dry stock sheds for months before use, etc., are all still insufficient to permit fine grinding.

The best illustration of really fine grinding and of proper preparation for it was found at the Chicago Heights, Ill., plant of the Ludowici-Celadon Roofing Tile Company. They employ a rotary dryer, consisting essentially of a boiler shell about 4 feet in diameter by 30 feet long, supported near its ends, in a nearly horizontal position, by roller bearings.

Provision is made to rotate the dryer by a gear wheel encompassing the shell and driven by a pinion near the discharge end. The shell is inclosed in a brick furnace, with space left in which the heated gases travel around and encircle the entire mill. The heat is supplied from coal-fired furnaces along the sides of the discharge end.

Formerly the gases of combustion passed directly through the mill, bathing the clay in their travel, with water vapor, carbonic acid, soot and sulphur fumes. The effect of this was believed to be responsible for a scum or efflorescence of sulphates on the burned ware, so the present rig was devised, whereby the gases of combustion do not come in contact with the clay at all, but pass along the outside of the shell and up the stack at the feeding end.

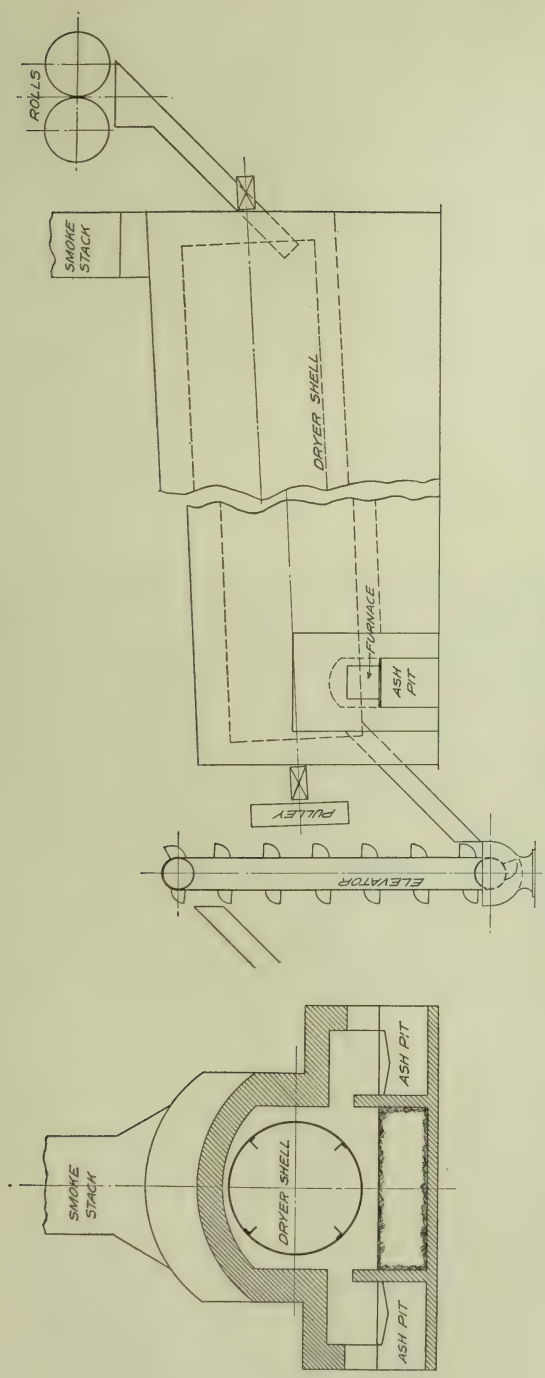

Fig. 60—Clay Dryer, substantially as arranged at the Chicago Heights plant, Ludowici-Celadon Co.

As the clay comes from the conical stone-separating rolls, in a fairly well shredded or disintegrated condition, it falls upon the inclined chute shown in the cut, and passes directly into the dryer. The dryer shell is inclined about one and one-half feet in its length, so as it rotates about 10 or 12 revolutions per minute the clay gradually works on through its entire length, being continuously picked up by four flites or blades, shown in the end section. These flites carry the clay nearly to the top of the shell before letting it fall, thus constantly stirring the clay up and exposing it to heat and air circulation. As the clay slowly reaches the hot end of the dryer, it attains a temperature of at least 212° F., although no attention is given to this point, except to see that the clay is perfectly dry at all times.

As the clay leaves the dryer it is caught up by a short cup elevator that discharges into the nine-foot dry pan.

A similar, but less efficient, installation has recently been put in by the Detroit Roofing Tile Company. In this case, they use three furnaces under the rotating cylinder.

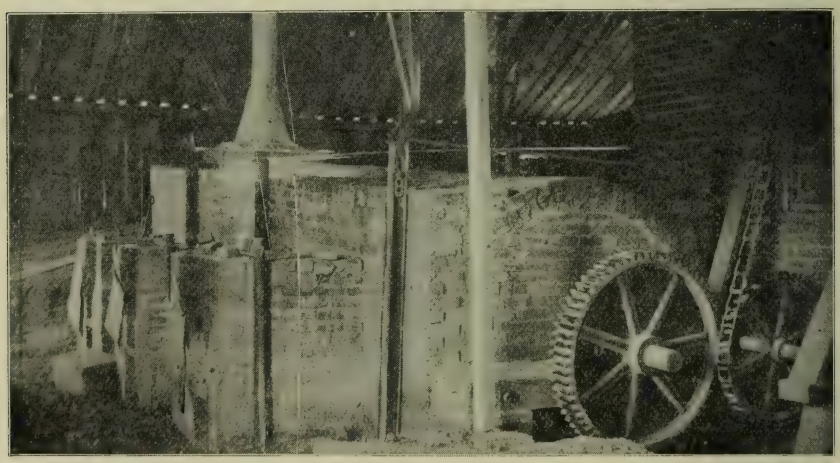

Fig. 61—Home-made Rotary Dryer installed by the Detroit Roofing Tile Co.

Such dryers, home-made in the two instances cited, but readily procurable from any one of a dozen prominent engineering concerns, especially those that cater to the cement manufacturing industry, are efficient. Their first cost, if home-made or built by a local shop from old boiler shell as a basis, may be kept small—under $1,000. If bought from a proprietary dryer firm, with furnaces and special feed apparatus, it may run from $2,000 to $4,000, according to dimensions and capacity and guaranteed evaporation. But by their use many clay works that limp along on one-third or one-half output every rainy day and close down all through the bad winter weather, could be made to turn out a good day's work all the time.

The cost of the treatment is comparatively slight. The power required to rotate the heavy cylinder is probably less than five horse power in some cases, and under fifteen in any that would be needed in a roofing tile plant. The fuel varies according to whether it passes through the dryer or merely around it, from one ton to three tons per day, or its equivalent in oil or gas. The feeding and discharge can readily be made entirely mechanical. The labor of operation may be confined to firing the furnace and this is done by automatic stokers in the Cummer and other good types. On the basis of drying fifty tons per day, and using two tons of coal, a fireman and ten horse power, the cost would normally not exceed 20 cents per ton and might easily be nearer 10 cents.

This kind of treatment is not a common thing, although its value is apparent and unquestionable. It happens, however, that the effect of this drying treatment is more complex than at first imagined, and that results are obtained from it which were not in the least anticipated by those who first installed it. This subject has come to light through the researches of Prof. A. V. Bleininger,[1] of the University of Illinois and the United States Geological Survey,[2] advance sheets of whose bulletin, in collaboration with Layman, have very kindly been furnished for notice in this report.

In the above article it has been shown that by taking a clay of high shrinkage, one which cracked so badly in drying that it was commercially impossible to work it, and preheating it at a temperature varying from 100 to 200 degrees above boiling point of water, it was possible to so reduce the shrinkage that the clay could be safely worked.

The test was applied to a clay found near Urbana, Ill., which is extremely fine grained, very sticky and plastic, but of low bonding power. Small samples of the clay were heated at 100, 200 and 300 degrees centigrade; after pulverizing and screening, the clay was tempered and wedged, then made into bars 10 inches by one-half inch by one-half inch. At the same time bars of the unheated clay were also made.

It was found that the bar made from the unheated clay warped very badly, and the bar made from the clay heated at 100 degrees centigrade did likewise. The bars made from the samples heated at 200 and 300 degrees centigrade showed very little warping.

The linear shrinkages were as follows:

Unheated clay	10.3 per cent.
Clay heated at 100° C	9.7 per cent.
Clay heated at 200° C	7.3 per cent.
Clay heated at 300° C	7.1 per cent.

Thus it is plain that a marked improvement was made in the shrinkage by preheating. It was noted that the clay heated at 100 de-

[1]Publications of the Univ. of Ill. A method of making possible the use of the Illinois Joint Clay. A. V. Bleininger and F. E. Layman. 1910.

[2]Owing to transfer of work, this bulletin was finally brought out by the Bureau of Standards.

grees was still sticky, while those at 200 degrees and 300 degrees had lost that characteristic property.

It will also be noted that very little decrease was made in the shrinkage between the 200 degree and 300 degree samples, hence it would be probably useless to carry the heating up to the latter figure.

They also went further with the work, making up samples in which varying per cents of the heated and raw clay were used, giving the following results:

TABLE No. 34.

Results of Preheating Treatment of Illinois Joint Clay.

Kind of Material.	Amount Tempering Water in Per cent. Dry Weight.	Drying Shrinkage in Per cent. Volume.	Burning Shrinkage in Per cent. by Volume.	Drying Loss in Per cent.	Burning Loss in Per cent.	Total Loss in Per cent.
Raw clay	33.5	41.2	21.1	32.	15.	47.
25% heated, 75% raw ..	32.0	39.1	21.	26.	9.1	35.1
50% heated, 50% raw ..	31.9	35.8	21.	15.3	11.0	26.3
75% heated, 25% raw ..	31.0	34.1	20.9	9.7	12.9	22.6
Heated at 200° C.....	29.9	29.3	20.6	0.5	4.0	4.5

From the above results it is apparent that the preheating of the clay has greatly decreased the drying shrinkage, the difference being 11.9 per cent. in volume, or nearly 4 per cent. linear shrinkage.

It will also be noted that a decrease in the burning shrinkage has also resulted from the preheating. The total volume shrinkage is decreased from 62.3 per cent. to 49.9 per cent, a difference of 12.4 per cent. The linear shrinkage has been reduced from 20.7 per cent. to 16.6 per cent. It will be noted that the shrinkage and losses decrease roughly with the increase of preheated clay. The writers also say that the sticky nature of the clay has been destroyed.

As to the cost, preheating can be carried on economically in properly constructed rotary dryers, either fired directly or making use of the waste heat from kilns. Quotations of two firms on the cost of dryers for such work were obtained. One firm recommended a rotary dryer, heated by direct firing, sixty inches in diameter and forty feet long, incased in brick. The cost of the dryer complete was $3,000, less freight.

The machine would dry fifteen tons of clay per hour, requiring eight to twelve horse power to operate, and for a material containing fifteen per cent. moisture the fuel consumption would be about 500 pounds of coal per hour. It was estimated that the cost per ton for preheating would be ten cents, including labor and depreciation.

A second firm gave the following figures: The cost of the dryer, $3,500; erection, $600.00; power required, 20 horse; fuel consumption.

60 pounds of good coal per ton of clay. The cost of drying was estimated at twelve cents per ton.

As many of the standard roofing tile clays discussed in Chapter III have rather high shrinkages, and would be improved if the same could be reduced, it was thought well, in view of the facts set forth in the above paper, to take a number of roofing tile clays of the highest drying shrinkage, and put them through the same tests used by Bleininger and Layman.

The tests, as carried out for this report, were conducted on five clays, numbers A, E, F, H and L, respectively, which were first ground to pass a 20-mesh screen. Several pounds of each were put in shallow pans and placed in the muffle of a Caulkins kiln, and the gas lit. By means of a pyrometer, the temperature was maintained for several hours at 200 degrees centigrade or above. At the end of this time the clays were taken out and cooled. It was found that they had materially changed in color, nearly all of them, regardless of the original color, assuming a light brick-red color. The clays were then tempered, and allowed to stand for forty-eight hours before wedging carefully and making into trial pieces two inches by two inches by three-fourths of an inch thick. The designation of the sample and marks 50 mm. apart were carefully stamped upon each test piece. They were weighed, and then placed in oil, and after soaking for twenty-four hours, were carefully measured for their volume in the Seger volumeter. They were then dried, reweighed, and new measurements of the shrinkage taken after complete saturation in oil. The following results were obtained:

TABLE No. 35.

Showing Differences in Linear and Volume Drying Shrinkage of Clays in Their Natural Condition, and the Same Clays Heated at 200° C.

Designation of Clay.	Volume Shrinkage of Natural Clay.	Volume Shrinkage of Dried Clay.	Difference in Favor of Dried Clay.	Linear Shrinkage of Wet Clay.	Linear Shrinkage of Dried Clay.	Difference.
A	13.47	11.63	1.84	3.94	3.70	0.24
E	12.43	11.10	1.33	3.94	4.03	0.09
F	12.96	7.55	5.41	4.03	2.44	1.59
H	19.36	12.52	6.84	6.00	3.98	2.02
L	16.96	13.61	3.34	4.88	4.52	0.36

Designation of Clay.	Calculated Linear Shrinkage of Natural Clay.	Calculated Linear Shrinkage of Dried Clay.	Difference.	Plasticity Water in Natural Clay.	Plasticity Water in Dried Clay.
A	4.71	4.04	0.67	16.01	18.19
E	4.33	3.85	0.48	16.80	19.73
F	4.52	2.58	1.94	19.08	17.18
H	6.92	4.36	1.56	19.83	20.00
L	6.01	4.76	1.25	16.67	17.26

From the foregoing table, it will be observed that the volume shrinkage has been reduced in every instance by the heating of the clay, clay H being reduced by a total of 6.84 per cent., while clay E was affected the least, having been reduced only 1.33 per cent. The linear shrinkages, with one exception (clay E), check the volume shrinkages in so far as they show a general decrease of shrinkage by the heating. The exceptional case of clay E is no doubt due to error in making the small linear measurements, because the volume shrinkage shows a small loss for this clay. It will furthermore be noted that the calculated linear shrinkages check the measured shrinkages in a general way.

The table on page 745 gives the further data obtained on the fire shrinkage of the same five clays.

It is difficult to interpret the fire shrinkages,as they fluctuate widely between clays and in the same clay itself at different temperatures with no clearly prevailing tendency. But the fire shrinkages of any clay are the least worthy of credence of any measurements obtained from the test, as they are the point where all irregularities of measurement, treatment or inherent peculiarity are sure to be lodged. The total volume shrinkages show in general what the drying shrinkages do—viz., a clear tendency to reduction by the preheating treatment and a variable degree of sensitiveness to its influence in different clays.

It was observed during the tempering of the predried clays that they had a tendency to work "short," or, in other words,after the manner of meal. Therefore, a comparison of water required to develop plasticity was made. It will be noted that the samples that were preheated have with one exception, clay F, taken more water to develop their plasticity than the clay in its raw or natural condition, which is very surprising in view of the reduction in shrinkage.

While no actual data were obtained on the rate of drying of these trials, it is firmly believed that, owing to their granular condition, they dried very easily and at a much more rapid rate than in the case of the same clays in their raw condition.

The fact that a clay like H had its volume shrinkage on heating reduced 35.33 per cent. and its linear shrinkage 33.51 per cent., or in other words over one-third of the total amount, should convince the most skeptical that there are great possibilities in this preheating treatment for some clays. The findings obtained in this work throw no new light on the work of Bleininger and Layman, except to show that their process applies to other clays than those studied by them and that it does not by any means apply to all with equal force. Some clays are evidently but little affected. Much fuller and more careful investigations on this subject are in progress in the U. S. Geological Survey laboratories at Pittsburgh, under direction of Professor Bleininger, where the cause is being earnestly sought for and the behavior of different clays at different temperatures is being studied.

TABLE No. 36.

Showing Differences in Shrinkage in Burning Between Clays Subjected to the Preheating Treatment and the Same Clays Without This Treatment.

Designation of Clay.	Temperature of Burning Expressed in Cones.	Total Per cent. Volume Shrinkage of the Clay without Preheating.	Total Per cent. Volume Shrinkage of the Clay with Preheating Treatment at 200° C.	Reduction of Total Volume Shrinkage by Preheating.	Per cent. Fire Volume Shrinkage of Clay without the Preheating Treatment.	Per cent. Fir Volume Shrinkage of Clay After Preheating Treatment.	Variation of Volume Fire Shrinkage Between Preheating and Untreated Clay
A	09	16.50	13.92	2.58	1.648	1.269	—0.379
	07	22.17	20.02	2.15	5.370	4.526	—0.844
	04	28.81	27.31	1.50	9.130	8.025	—1.105
	01	29.94	27.92	2.02	9.340	9.105	—0.235
E	09	13.41	12.88	0.53	0.424	0.688	—0.244
	07	14.58	12.04	2.54	0.138	0.855	—0.717
	04	13.56	13.09	0.47	0.859	1.220	—0.461
	01	18.51	15.15	3.46	2.890	2.490	—0.400
F	09	13.05	8.51	4.54	0.566	0.185	—0.381
	07	17.60	12.08	5.52	2.710	2.115	—0.595
	04	21.18	14.06	7.12	3.760	3.809	—0.049
	01	23.80	15.60	8.20	5.605	4.163	—1.442
H	09	20.43	13.04	7.39	0.327	0.494	—0.167
	07	21.84	15.01	6.83	0.659	1.756	—1.097
	04	23.97	21.32	2.65	3.144	1.070	—2.074
	01	27.14	20.52	6.62	4.988	4.733	—0.255
L	09	21.87	19.84	2.03	2.85	3.57	—0.72
	07	24.93	21.93	3.00	4.67	Bloated	.....
	04	swelled	swelled	.....	Bloated	3.910	.....
	01	swelled	22.41	.....	3.630	3.480	—0.150

With the above figures at hand it would seem certain that it is within the reach of the roofing tile manufacturers of the country to install and operate such preheating equipments. The results shown in the original article and those obtained from the study of actual roofing tile clays show highly desirable results in most of the clays tried

The relatively small tonnage of material used per day by the roofing tile manufacturers, and the price obtained per ton for the finished ware, make it entirely within the scope of possibility for them to preheat their clays. It certainly would be of great advantage to those working highly shrinking clays to preheat all or part of their clay at least. By the utilization of waste heat from the cooling kilns the cost of the treatment could be reduced to a few cents per ton, even putting it within the reach of the brick manufacturer. It is beyond doubt that those who have been using rotary dryers for purely drying purposes, have often obtained something of the value of this preheating treatment without definitely recognizing it, at least for a part of the time, if not constantly. One such instance is on record, where a brick manufacturer had almost no trouble from cracking in winter when his dryer was necessary to grind the clay, but had constant trouble in summer, when the clay was dry enough to grind without the dryer being used.

Screening.—The purpose of screening is to set a limit to the maximum size of mineral particles which will be allowed to enter a piece of clay ware. As the coarsest particles in a ground mixture are also apt to be the hardest and also of different chemical composition from the general matrix of fine material which contains the plastic aluminous matter we think of as clay substance, it follows that these coarse particles are both difficult to grind finer and are the most injurious to the homogeneous character of the clay if they are not ground and made to blend well into the matrix. Particles of limestone, carbonate of iron, gypsum, pyrites, coal, etc., are all able to ruin the appearance of the product unless thoroughly disseminated by fine grinding.

Screening is therefore necessary to establish a limit beyond which particles cannot enter the clay body, except by accident. It is a very necessary part of the process of homogenization, of which grinding and tempering are the two principal steps.

The operation of screening clays is more troublesome than that of screening other dry powders, because of the sticky nature of clay grains when damp, as explained under predrying. For this reason, the actual size limit used in clay plants is often much greater than is desired by the manufacturer, because without predrying he cannot either grind or screen effectively. By thoroughly drying a clay in advance, fine grinding in the dry way becomes possible to any limit needed for the most exact homogeneity of product required for any commercial uses.

The maximum size of particles permissible in roofing tiles is probably somewhat less than for other parallel industries like paving brick, face brick, sewer pipe, etc. In general, a screen of 8 meshes per lineal inch, or 64 holes per square inch, with the wires which make these meshes occupying about one-third of the space, represents commercial fineness for brick and pipe. That makes the diameter of a particle to pass these holes not to exceed about 0.08 inch, though 0.10 would be likely to be found due to irregularities of weaving of the wire cloth. But besides wire cloth, screening is done by perforated metal plates, with round holes or slotted holes, and latterly by piano wire screens with long slots, practically free from cross wires, so that the particles of flaky shape may, theoretically at least, pass the screen with far larger dimensions than 0.10 on one or more of their axes.

The expression "ten mesh" or "eight mesh" does not, therefore, carry a clear and unambiguous meaning of size, for the size of the wire must also be stated. Perforated metal with round holes makes a screen much slower to operate, but a much more exact standard of size.

Roofing tile clays in general are passed through from twelve to twenty mesh screens or equivalent. In one instance eighty mesh was used for a long time, but this is altogether unusual, and was also unnecessary for a product of the required grade.

Classification of Screens in Use.—In going over all the styles of screens in use, it is found that with two exceptions manufacturers are all using some form of the inclined screen, either stationary or movable.

Stationary Inclined Screens.—These consist of an inclined chute, the bottom of which is made of perforated metal or woven wire cloth, over which the pulverized clay passes by gravity. The size of the perforations and the angle at which the screen is hung governs the size of grain that will pass through it.

Should the screen be horizontal, particles the same size as the openings will pass through, but upon elevating one end of the screen so that the material attains a momentum, the particles passing through will become smaller and smaller as the angle of elevation increases.

Advantage is usually taken of this fact in constructing inclined screens, so that variations in their angle can be easily made. During the seasons of the year when the clay is damp and screening difficult the angle can be flattened to enable the material to more readily pass through. As the material becomes more dry later in the season, the screen can again be raised to its former angle. The manufacturer can thus keep up nearly his proper daily output, although this means, of course, a lowering of the standard of his wares as to homogeneity in bad weather, which is a practice full of danger to the reputation of the product. The stationary inclined screen gives much trouble through its tendency to become caked over with clay, especially when the clay is

damp. This means that the attention of some one must be given to the screen to keep it effective. Ordinarily a hoe or shovel worked backward and forward over the surface of the screen will partly keep it cleared of caked obstructions. Very often the work of keeping a screen clean is left to the dry pan feeder or some one else whose main duties are elsewhere. Visits to screens, up dusty stairs or dark ladders, are always likely to be at long intervals, for everyone is likely to dodge a disagreeable task if he can. It very often happens that one-third or one-half of the clay delivered to the screen from the grinder is being returned to the grinder as tailings because it cannot pass through the coated or clogged screen. The attendant will then make his way to the screen loft, and in desperation will attack the accumulation too vigorously, loosening large chunks of the caked dust, which slide down the screen and are likely to choke the tailings spout. This necessitates a shut-down of the pan while the obstruction is being removed.

The fixed incline screen was found in use in only one roofing title plant, the Huntington Roofing Tile Company, Huntington, W. Va. Their material, as mentioned before, is composed of two shales, one very plastic and the other very sandy. The proportion of the mixture was not obtained, but the screened clay appears to be quite high in free silica. A sandy clay is not nearly so likely to cake on a screen as a more fat, plastic one. It was also found that the mesh of the screen used here was sixteen, which is a little coarser than the average mesh used by roofing tile manufacturers. These two facts probably explain why it is possible for this firm to use this simple type of screen without prohibitive trouble.

Piano Wire Screen.—A rather recent form of inclined screen is called the "piano wire type," which has been in use for only a few years. As the name implies, the screen is made of heavy steel piano wires. These are strung parallel on a strong, substantial cast or wrought iron frame about two and one-half feet wide by six feet long. The wires are drawn to a high tension by screw tightening pins, and should be so firmly secured that they cannot slip. If this is not guarded, the screen becomes very inefficient indeed. At each end of the frame the wires are drawn over a heavy rod, which is threaded to suit the space required between the wires. By varying the pitch of these threads the mesh can be easily changed to suit the conditions under which the screen is to be used.

A threaded rod is also placed in the middle of the screen, and sometimes two are used to steady the wires and prevent them from spreading apart when pieces wedge between them. The screen is usually set or hung so that the angle can easily be changed to meet changes in the condition of the clay. A very satisfactory expedient for preserving the distance between the wires without making any superficial obstacle for the clay to lodge against or start to cake upon, is to solder strips of tin on

the lower side of the wires at intervals of a foot or so apart. The solder can be scraped smooth with the top surface of the wire very easily; it takes up but little room, and is easily repaired at any time.

The increased rigidity of the wires is very important, indeed, in preventing wedging apart and consequent irregularity of output. The claims for this style of screen are: First, it has a large screening capacity, while giving very little trouble from clogging or packing of the clays; second, it does not cost anything for power to operate it; third, it requires but very little head room to house it.

The above claims are all well founded, and without question for some classes of clay product this machine is a very valuable invention for the trade.

Fig. 62—Piano Wire Screen.

As applied to the roofing tile industry, a strong objection has been raised against it. This objection is that it is impossible to secure a close enough accuracy of sizing for roofing tiles, owing to the wires stretching and becoming loose, sagging down and allowing large grains of hard material to pass through.

Three plants were found to be using the piano wire screen with more or less success, depending on the nature of their raw material.

One plant, using a very soft, easily slaking shale, was getting very good results. The very next plant visited, which was working a very hard, sandy shale, was getting anything but good results, the surface of the tiles being rough and unsightly at close range. One of the largest plants had at one time installed two piano wire screens, and after giving them a thorough test taken them out on account of their requiring too much attention to keep the product as uniform as is desired.

The "Perfect" Screen.—This screen seems to be in most favor with the roofing tile manufacturers. It is made by the Dunlap Manufacturing Company, of Bloomington, Ill. It is a modified form of the inclined screen. The main difference is that the screening surface, composed of plates of perforated metal, is continually in motion on an endless chain.

The object of this device is to bring automatically every part of the screen surface over a rotary cleaning brush instead of depending on its being done by hand, as is the case with all stationary inclined screens. The perfect screen is made up of sectional screen plates, attached to sprocket chains on each side. These chains travel upward

on an inclined frame-work around sprocket wheels at the top, back on the lower side, etc. There are four points of attachment to each plate, two on each side. One attachment is at the forward edge of the plate and the other is at the center, permitting the plates to travel around the sprocket wheels without binding. The clay from the grinding machine is thrown onto a spreading board at the upper end of the screen. After leaving the spreading board, the clay slides down over the surface of the screen plates which are travelling in the opposite direction, or against the down-coming stream of clay. The clay, passing through the perforated plates, drops onto a floor which is betwe n the two lines of travelling plates. The floor is more highly inclined than the screen proper, thus facilitating the delivery of the fine clay at the lower end where it falls upon the reverse side of the perforated plate. As the plate revolves around the sprocket wheel, the clay is dumped off into a bin below. The tailings flow over the lower end of the screen into a spout which returns them to the grinding machine. Curtains of loose aprons of canvas are hung down, touching the surface of the up-travelling screen plates. These retard the down flow of the clay, and have an effect similar to that of rubbing material through a screen by hand.

On the other side of the frame work is a rotating brush, held in contact by weights with the face side of the screen plates as they pass downward on their return trip. By adding more or less weight to this brush, it can be made to brush harder or easier, as the condition of the clay requires.

The screen plates in this machine are most usually of perforated metal, although piano wire plates can be furnished. In the metal plates, the perforations are usually slotted and are placed in rows herring-bone fashion, thus causing a greater resistance to the clay passing over it.

The entire screen is so hung that its angle can be changed in a very few minutes.

The rate of travel of the screen plates is quite slow, not over three or four feet per minute, so that the wear on the machine is very slight and the power used is insignificant. The screens are made in three sizes, the medium size is the one most used by the roofing tile manufacturers. This size will easily care for the clay from a single nine-foot dry pan, and screen it to the fine mesh desired for roofing tile.

In five plants, six of the above screens were found in use, the range of the meshes being eighteen at three plants and twenty at the two others. No trouble was found in obtaining a sufficient amount of screened clay of this fineness. Owing to the constantly revolving brush, the room where this screen is used is for the most part rather dusty. The sweepings are generally allowed to fall to the floor instead of being caught in a chute and returned to the pan. This latter point

is not a fault of the screen in question, but merely represents poor construction on the part of the builder. There are a number of distinct advantages in this type of screen over others.

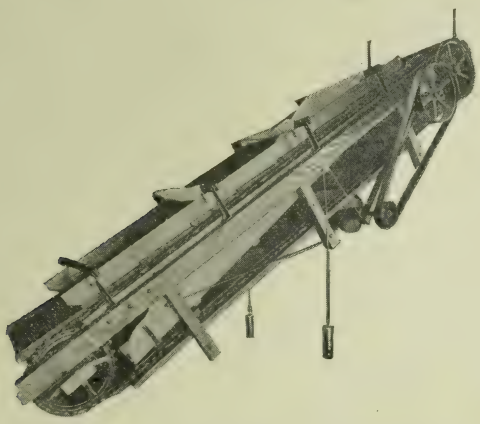

Fig. 63—The "Perfect" Clay Screen.

Its automatic cleaning is simple, effective and cheap. It requires almost no attention, and it has a large capacity, and will screen finer clay than other inclined screens because it is always clean.

On the other hand it requires some power to operate it, though not very much. It makes a good deal of dust, and is large, and requires considerable head room. None of these objections are serious.

Centrifugal Screen.—There yet remains to describe a screen found in the plant of the Ludowici-Celadon Company, at Alfred, N. Y., which is out of the ordinary in the clay industry.

It consists of a large funnel-shaped cage or receptacle, about four feet high with a diameter of nine feet at its upper or large end. The shell of this funnel is made of perforated metal. Vertically through the center of this cone passes a shaft. At the lower end it extends through and rests in a step below the funnel. The upper end passes through a bearing and is equipped with bevel gears, to be driven by power. The conical shell is fastened to the main upright shaft by means of spiders, and hence revolves with it. The clay to be screened is fed into the center of the rapidly revolving cage. Upon striking the floor it at once begins to move up the sloping sides of the screen by centrifugal force, the fine clay being carried through the perforations while the coarser material travels on up the sides until it passes out over the top where it is caught in a trough and returned to the dry pan. The screened clay is intercepted by an exterior conical shell or casing that encircles the screen. Sliding down this floor, it enters an elevator boot where it is elevated to the storage bins.

It is claimed by the owners that this screen has for a number

of years given excellent satisfaction. In fact, the first one proved so satisfactory that the company later added a second one, though of smaller size, the latter one being only six feet in diameter at its large end.

This type of screen, possibly differing in some details, has since been taken up by the manufacturers of clay machinery and applied to other plants.

In the Alfred plant, it is somewhat unfavorably situated, being set on the second floor on a level with the clay bin, and thus requiring two elevators to serve it, one to bring clay to it and the other to carry the fine screened product up to the top of the bin near by. This is a local fault and in no wise diminishes the effectiveness of the machine itself.

Other Types of Screens.—There are many other screens in use in other clay industries, which might have been applied equally well to roofing tile manufacture. Shaking or vibrating screens, rotary or cylindrical or conical screens on a nearly horizontal axis, gyratory screens, pneumatic sizing by means of air blasts, are some of the more important. None are especially more effective than those discussed.

The screening done by the Ludowici-Celadon Company at their Chicago Heights plant is unusual, both as to method and fineness. After passing the pan, the clay is caught up by a cup elevator and carried to the third story of the building, where it is thrown onto a pair of inclined gravity screens, constructed like a letter A, having an angle or opening of about 90°. These screens are joined at the top, or apex, and are about thirty-six inches wide by eighteen feet long per side, thus giving a screening area equal to a single screen thirty-six inches by thirty-six feet.

The advantage claimed for this arrangement is that a lower building is required than if built in one single screen. There is one disadvantage however. The screened clay that falls through one end of the screen must be conveyed over to the other side in order to have it dumped in the same bin. This conveying is done by means of a belt conveyor.

The mesh of the screen was found to be one twenty-eighth of an inch, but with this extremely fine mesh set at an angle of forty-five degrees, the actual degree of fineness of the clay screened is nearer to forty or sixty mesh than twenty-eight.

It would seem next to impossible to screen the large tonnage used by this company through a screen of the above type and size and to such an extremely fine mesh, and under ordinary conditions it would be wholly so, but when the condition of the clay that goes to the screen is considered, it is not so hard to understand. The clay comes from the rotary dryer perfectly dry and so hot that after it passes the dry pan, and has been elevated and screened, it still contains so much heat that one can scarcely hold it in the open hand.

Under no other conditions would it be possible to screen so large a quantity of dry clay to so fine a mesh, which is much the finest used by any roofing tile plant in the United States.

Studying briefly the results accomplished by this fine grinding, the heretofore mixture of rocky gravel, clay and sand has been made so fine and intimately mixed that it is, roughly speaking, a definite compound. That is, it will act more nearly like a single substance than as a mixture of several independent ingredients. The most troublesome material, limestone, has been reduced to such fine grains that it has lost its power to cause popping. It still makes the body a little lighter in color, and possibly helps to form sulphate scum on the surface of the tiles if brought in contact with sulphur gases in the kiln or dryer.

While the use of glacial clay like this for roofing tile manufacture has been proved possible by this company, still it is not to be recommended, unless it be in very rare cases, in a territory where all other clays are lacking. Owing to their variable composition and the great care and expense necessary to prepare them properly, their use from an economical standpoint is to be condemned.

As a rule glacial till runs so high in lime content that it is impossible to vitrify it safely. High lime content in a clay has that peculiar and treacherous feature of causing a very short vitrification range.

So narrow is the limit between a good hard body and a vitrified one, speaking, of course, of limy clays, that the trade has not at its command a kiln permitting of regulation close enough to burn such clays to vitrification with safety.

This means that the burning of glacial clays must stop at a point well below the complete vitrification point. In other words, the body must be left porous.

Again, it is not likely that a clay of glacial origin will, with its various ingredients, burn to the good clean red so much desired for roofing tiles. This means that to obtain a good color the manufacturer must go to the expense of buying a good red burning clay elsewhere, and using it as a slip coating over the face of the glacial clay tile.

This false covering is only a makeshift, adding greatly to the cost of production, and unless the body and slip fit well, they are likely to separate and peel. Also accidental chipping of the tile discloses its light colored body beneath the slip and keeps customers irritated over trifling defects not at all visible after the tile is in position.

So, though this company deserves much credit and admiration for the way it has overcome the disadvantages of a badly selected clay, by thorough mechanical treatment, still it is under a handicap in using it.

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Summing up the various screens in use at the roofing tile plants of this country, the following list is obtained:

TABLE No. 37.

Showing Various Types of Screens in Use Among Roofing Tile Plants.

Kinds of Screens.	Number Plants Using.	Number in Use.
Gravity, inclined	3	3
Piano wire, inclined	3	3
Shaking	1	1
Perfect clay screen	5	6
Centrifugal	1	2
None at all[1]	1	0

[1]Using soft clay in a wet pan.

Tempering.—Tempering means the adjustment of the water content of a clay to the forming operation which is to follow. In the dry press the amount of water used is small, and in fluid casting the amount is very large, but the same word "temper"applies to the adjustment of the dry press powder for pressing and the thickness of the slip for successful casting.

In ordinary clay working processes, depending on the use of clay of plastic or pasty consistency, tempering means the regulation of the water content so that this plastic quality may be most fully or at least sufficiently developed. This involves not merely the adding the water, but in securing its even distribution over and among all the particles of the clay.

The modern conception of a plastic clay is that of a very stiff fluid, in which every grain of solid matter is surrounded by a liquid film or envelope, so that the particles are virtually in a state of fluid suspension. This has been discussed in Chapter III in connection with shrinkage and water of plasticity.

It is evident that to get a piece of clay into such perfect temper that the preceding conception becomes true or approximately true, calls for a very complete disintegration of the solid particles, so that they may readily assume the new relation towards each other under the influence of water.

The ease with which different clays take up water and assume this state of fluid suspension, or plasticity, varies very widely. The chief causes of variations are physical. They do not center so much in the proportions of the "clay substance" or plastic elements vs. the sand or anti-plastic elements as was formerly believed. It has been shown that many rocks, powdered finely, yield more or less plasticity, and that

only a small amount of plastic clay may convert a large amount of otherwise anti-plastic matter into workable shape. The purest clays are often of low plasticity.

The important factors affecting the plasticity of clays are those of pressure, consolidation, heat and infiltration of hardening or cementing substances, like bitumen, ferric hydroxide, or carbonate of lime. In the clays of the present time or Pleistocene geological period, like river flood-plain clays, glacial till and lake-bed clays, consolidation by pressure is at its minimum. These clays are all superficial and have never been covered by deep deposits or great weight. They are constantly being opened up by the infiltration of surface water, and frost, and vegetation. Such clays are always easily brought to as much plasticity as their mineral make-up permits. They temper easily.

Clays which had their origin in geological periods preceding the Tertiary are always much hardened by the vicissitudes of heat and pressure to which they have at various times in their long existence been subjected. These clays are generally hard and rocklike unless softened superficially by weathering. Tempering such clay means breaking down the close, dense structure given by pressure and heat, and oftentimes dissolving out or loosening up the hardening solutions which have permeated the masses of mineral grains and filled the voids with a hard cementing filler.

Clays which had their origin in Tertiary or later periods, down to the Pleistocene or present period, are as a rule much less hardened or fossilized, and can as a rule be made plastic with comparative ease, though they are by no means like the present clay, and locally have often been hardened as completely as the carboniferous or Devonian clays.

Whatever the structure, and no matter how great the hardening produced by age or pressure or chemical infiltrations, it is possible to restore the plasticity of a clay by mechanical treatment, provided the plastic elements have not been destroyed by heat. Clay, when burnt, can never be made plastic again, and in nature temperatures of far less than red heat have so altered the clay minerals that their capacity to assume the plastic state is destroyed. Slates, for instance, are, mineralogically, exactly like shales, except that they have lost three or four per cent. of their chemically combined water, and are non-plastic in consequence. This change was due to heat far below redness.

From the foregoing it is evident that the amount of mechanical work to be expended in getting clays into the same physical condition of plasticity is sure to vary greatly. With some it merely means stirring up with a little water—the old-fashioned vertical horse pug mill used on soft mud hand brick yards; or still more elementary, the shallow soak pits, and the tramping of the clay with the bare feet of laborers, as is still done in Mexican roofing-tile yards, amply sufficed. With

others an intense stirring, under pressure, is needed, as is given in the better class of pug mills. With others, nothing less than long-continued grinding in the presence of water, under heavy mullers, will succeed in breaking down the rock structure of the fossilized clay.

In general there are only two mechanical methods available—pugging vs. wet grinding. The old-fashioned, primitive foot-tramping cannot be considered as commercially possible today in a civilized country.

Pug Mills.—Their general features are so well understood that they need not be described. There are many variations in structure, which are of benefit or otherwise, and of these it is necessary to speak. The dimensions run from six to twenty feet in length and from two and one-half to four feet in diameter for horizontal mills. Vertical mills are seldom used today outside of the pottery industry. The pug shaft is carried at the outlet end by a simple bearing, while at the inlet end provision must be made to not only carry the shaft but at the same time to provide for the heavy end-thrust produced by the work of moving the clay forward and forcing it out through a limited aperture. This is accomplished in the more simple mills by having the boxing cast with one end closed. This boxing, of course, must be very securely held in position, hence it is usually made a part of the rear frame of the machine. The cap or end of the boxing is turned out true and smooth, then a bronze disc of the same diameter as the shaft is slipped into the bearing. The end of the shaft now is brought into contact with the bronze disc. As a rule the entire bearing runs in oil in order to reduce the friction as much as possible and keep the bearing from heating.

Pug mills are made with single shafts like that just described, and double shafts revolving toward each other.

At the outset it should be understood that the work of a pug mill is not that of grinding a clay, but only of mixing and stirring it. If given a clay with only a slightly hardened structure and slightly latent plasticity, it is possible by means of a single shaft pug mill to develop the plasticity sufficiently for most clay working purposes; but should the clay be a little more hardened, it would be better to use the double shaft mill, or possibly a very long single shaft mill.

The double shaft mill, while not giving twice the pugging action of the single mill, has a much greater capacity, thus making it possible to hold the clay under the action of the stirring knives much longer. Also by using a less number of propelling knives, or knives of a lower pitch with an increase of simple cutting and stirring blades, it is possible to regulate the passage of the clay through the pug mill until it has been throughly mixed.

Pug mills are also built open top and closed top, the difference being that the pressure applied to the clay in mixing and cutting it by the knives is limited. The clay is free to move upward, and thus relieve the pressure. But with mills of closed top the delivery of the clay be-

comes like that of an auger machine, and uses a large amount of power and rubs the clay and water together so much the more intimately.

No pug mill exercises a grinding effect on a clay. Particles of a single mineral are rarely if ever reduced in size by pugging. Agglomerations of particles of minerals, when not held together by some cementing material, may soften enough by water to come apart under the stirring action of the pug mill, but if they are at all hard or consolidated, they will not.

The pug mill is fit, therefore, for tempering unconsolidated or recent clays of readily plastic character. It is out of place with clays of difficultly plastic nature.

It is possible to use pug mills alone with no grinding machinery whatever in the case of some soft alluvial and glacial clays. Also, it has been found that many clays, by dry grinding and careful sizing of grains to exclude all coarse matter, will develop a moderate plasticity by pugging sufficient for stiff mud manufacture. Thus pug mills are in use in hundreds of plants merely as stirring machines, the dry pan breaking up the rock structure and producing a powder, the screen keeping the maximum coarseness under control, and the pug mill mixing the powder with water. Wherever this process gives a sufficient plasticity it should be used. It is cheaper, easier, simpler in every way than the wet grinding. But it will not do the work of wet grinding in dealing with difficult clays, and should never be expected to.

Wet Grinding.—The use of the wet pan as a preliminary grinder, beginning with the crude clay direct from the pit, has been briefly discussed at the proper place. The use of the wet pan as a tempering machine, with grinding thrown in incidentally, requires a little different construction and radically different operation.

Wet pans for tempering previously ground and screened clay use, generally, mullers varying from three to eight inches in face, while initial grinders usually have mullers with from ten to eighteen inch face. The crushing action is magnified in the latter, the cutting and mixing action in the narrower wheels. The weight of the muller is not necessarily less, for it is very common to see wet pan mullers with extra large hubs, which are added for their weight, it being desired to have the mullers cut through the mass of clay, and crush any particles that may be caught between them and the pan floor. The scrapers are also set differently, and are of different size, being designed as much to stir the mass as to direct it under the wheels. The use of large plows or scrapers becomes difficult with very plastic clays, for it requires excessive power to drive the pan, which is hard to drive in any case.

The pan is most usually located on the ground floor, immediately below the bin of screened clay. A tube of wood or iron, provided with a valve, or cut-off slide, leads down from the clay-storage bin to within two or three feet of the pan floor. The operation of a pan is about

as follows: The pan being run empty, the attendant opens the valve in the clay spout, and at the same time opens the water valve, letting a stream of water run into the pan. Only ten or twenty seconds are required to introduce a charge of from 600 to 1,000 pounds of ground clay and from 150 to 200 pounds of water. The stream of clay is then stopped, but the water is continued until the clay apparently becomes too soft and too sticky to use. As the grinding progresses however, this apparent excess of water soon soaks in and more water must probably be added. If the grinding is continued a minute or so extra, additions of water must be let in from time to time, the excess being soon taken up by the grains of clay, as the subdivision proceeds. The original grains, if hard, would require but little water to wet their surface, but the finer they are ground, the more water will be needed to secure the usual apparent dampness of the same. When the clay is tempered to the proper degree, determined by the touch or sense of feel of the operator, it is emptied out as speedily as possible. The time consumed in tempering a charge varies from two to four minutes usually, three minutes is a fair average in all the plants in which this operation has been timed. Of course, with some hard clays, or in an industry consuming small amounts of clay only, the time per panful will be increased.

Unloading is done by a semi-mechanical, hand-actuated shovel in almost every plant where wet pans are used. A large shovel, pivoted to the frame of the pan on a ball and socket joint, or equivalent, is lowered into the revolving pan, against the direction of motion. The clay in its travel with the pan, rushes up the inclined plane of this shovel until it will hold no more. The amounts held are seventy-five to one hundred pounds at a time. The operator then raises the loaded shovel by bearing down on the handle, swings it over the rim of the pan and dumps the load onto a conveyor or elevator to be carried to the forming machinery. Automatic unloaders of many types have been made and used successfully. Plows, scrapers, revolving buckets, mechanically driven shovels, pans with sectional rims, discharging by centrifugal force, etc., have been tried—all successfully. The problem is not difficult, mechanically.

The fact remains that the old hand method still hangs on, and is set up by many as the great obstacle to the use of the wet pan.

Operation of Wet Pan.—The wet pan gives the most thorough tempering that it is possible to give clay. The grinding action is a very important feature, especially with hard, gritty clays. The handling of such materials in a pug mill is either impossible or requires the addition of a soft plastic clay to help it out or a long-aging period to permit softening to take place in order to make perfect ware. With the wet pan the same hard clay can in a few minutes produce as much

or more plasticity than could be developed by a pug mill treatment with unlimited time.

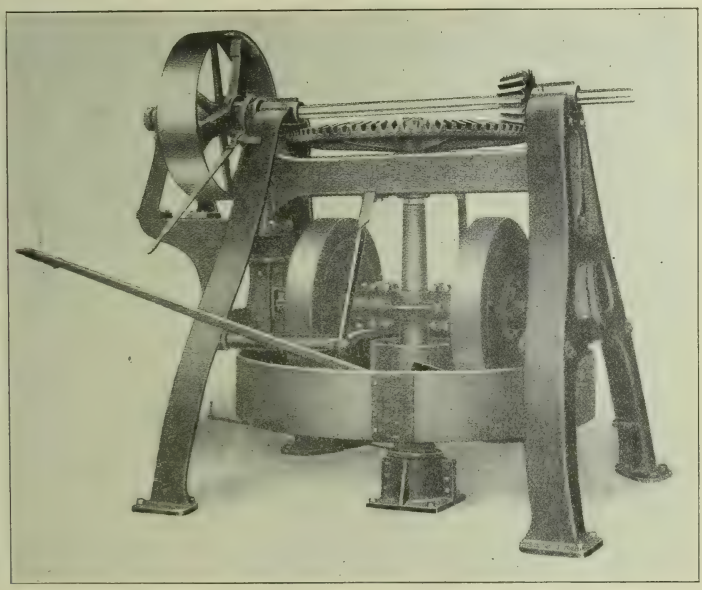

Fig. 64—Wet Pan with Shovel.

Should it be advantageous to mix two kinds of clays, the wet pan will do the work in a most satisfactory manner. The clays are actually blended until they form a new material, different from either of the two that were originally added to the machine in color and properties of burning. On the same class of work, the pug mill will only stir the two clays together, but will not in any way grind them one into the other as the wet pan would, and the color of the mixture is almost always specky, showing separate grains of both clays still maintaining their identity.

While the wet pan gives very excellent work as a tempering machine it has some objectionable points. Among them are the following:

First. Its cost of installation being about twice that of a pug mill, viz., $800 to $1,000.

Second. Its consumption of power. In most clays it requires two wet pans to prepare the clay for one auger machine making roofing tile, and if brick are to be made, three or four wet pans would be needed for a moderate auger-machine output. The actual horse-power used varies enormously with the clay, the charge tempered, the consistency or wetness desired, etc. But it is never low and probably runs from twenty-five to forty horse-power on the average, when it has a charge grinding. While unloading and recharging, the power consumption

drops and rises again, so that about one-third of the time is lighter duty and two-thirds heavy duty.

Third. The clay is tempered in batches, and even with the utmost care, it is impossible to always get each batch to the same temper. With some clays it will be found that they will absorb water so fast that it will be impossible to empty the pan quick enough to have the last of the batch of the same temper as the first. This means that the clay will go to the forming machinery in an uneven condition, giving more or less trouble, such as uneven flow through the dies and a variable shrinkage.

Fourth. The class of men required to operate them are hard to secure. They not only require a man with a keen sense of feeling and good judgment, but one of good physique also. Very often these two requirements cannot be found in the same person. It often happens that a man of light weight can determine the proper temper of the clay to a nicety, but will lack the necessary strength to operate the shovel continuously. The trouble is within the reach of mechanical methods however; where unloading devices are seriously desired, they will be found.

Fifth. The irregular load of a wet pan is hard on an engine. When two pans are in the same shop this usually regulates itself, as one is discharging and filling when the other is grinding.

While the wet pan has these bad features, it will be noted that they are largely of a mechanical nature. No fault can be found with the quality of work done by the wet pan, except as to possible variability of temper. This variability is also susceptible to mechanical regulation, by using weighing or measuring boxes for clay and water, instead of charging purely by judgment. The condition of the clay, day by day and hour by hour, would require adjustment in the quantity of water added per standard charge of clay, but this could easily be changed as found necessary and each consecutive charge of the pan would then vary only as the clay itself varied in initial water content.

In the preparation of roofing tile clays, too much stress cannot be placed upon the advisability of having the clay thoroughly prepared. Good tiles cannot be made from insufficiently tempered clays. In the case of soft clays, like alluvial or glacial deposits, it is possible to develop their plasticity by pug mill treatment without storing the clay in bins to age for several days. In the case of the fossil clays, like shales and fire clays, it will be found that only in the softer varieties can the tempering or pugging be satisfactorily accomplished by the pug mill.

Should the pug mill be used, it will be found in nearly all cases advisable to use the double shaft style, and then age the clay for a period depending on the hardness and other qualities of the clay or shale in hand.

TABLE No. 38.

Classification of Methods of Tempering at the Various Roofing Tile Plants of the United States.

Quality of Material to be Tempered.	Rolls and Pug Mill.	Pug Mill.	Wet Pan.	Both Pug Mill and Wet Pan.	Aging.
Shales	.....	.....	1 plant	.....	No.
Shales	.....	.....	.....	1 plant	No.
Shales	.....	5 plants	.....	.....	No.
Shales	.....	2 plants	.....	.....	Yes.
Soft Clays	.....	2 plants	.....	.....	Yes.
Soft Clays	.....	.....	.....	1 plant	No.
Soft Clays	1 plant	.....	.....	.....	Yes.

From the above table it will be seen that of the nine roofing tile plants using shales, only one is using wet pans exclusively, one other plant has both pug mills and pans in use, and seven plants are using the pug mills exclusively for tempering. It will also be noted that in only two plants using shale is aging of the clay being practiced. Of the soft clays used in the four plants, three are being prepared by pug mill treatment followed by aging. In the fourth plant, while the clay is not aged it is given a possible equivalent for aging, by first running the soft clay through a wet pan and then through a pug mill, before entering a combined pug mill auger machine for forming the clay bar.

It can be seen at a glance that the plants using soft clays are the ones giving the best preparation, while the plants working shales, a material that is slow to temper, are using the least pains to properly prepare their body.

Far more trouble in roofing tile manufacture is due to improper tempering of clays than is generally thought. The improper flow of the clay through dies, resulting in warped and checked tiles in the dryer and kiln, is one result. It will also be found that most shale clays which pass direct from the pug mill to the auger machine, or other forming machinery, will have a tendency to form a rough bar, with corner or side checks. This is due to the weakness or lack of tensile strength of the granular clay, the coarse grains of which act as so much non-plastic material.

Where tiles are made from clays direct from the pugging machinery, the harder grains generally will not have slaked or softened down in the limited time available since the tempering began. These grains subsequently soften in the dryer under the influence of time and heat. before the water is expelled. When they do soften, they not infrequently cause changes of volume leading to cracks, warping, pimples and similar troubles. Where no outward signs of disarrangement are visible, it is possible that the tiles will suffer distortion in the kiln as a

result of their defective preparation. Now had these same clays been prepared in a wet pan, using hot water for tempering, or had it been tempered in a pug mill with hot water, and then stored in bins to age, allowing the granular particles to disintegrate before being manufactured into tile, it is believed that less loss in the kiln and dryer would have been the result.

It is also believed that while the wet pan has some objectionable features, its use should be much more general in the roofing tile industry. The amount of clay used is relatively small and the price for the finished ware is relatively high when compared to brick, so that it is possible for the roofing tile manufacturer to prepare his clay better than in some of the other industries.

Aging Clays in Connection with the Tempering Process—The method is most popular and most likely to be used is the pug mill treatment. This, however, should be done in the best possible manner. To properly prepare clay by pug mill treatment, no better machine can be recommended than a combined double shaft pug mill auger machine. The only machine of this type found in use was that of the J. D. Fate Co., Plymouth, Ohio. Of the fourteen plants working in 1908, nine of them were using this company's pugging machinery. The clay should first of all be ground to eighteen mesh or finer, and when fed to the pug mill should be treated with hot water, in slight excess of that needed to produce the proper temper for working. As the clay is worked along by the blades or knives of the pug mill, each particle becomes wet in the hot water; as the clay passes from the end of the double pug mill, it is fed into the auger machine part of the mill. Here it is compressed and packed into a dense mass by the time it is expressed from the die. By a suitable cutter, it should be cut into blocks of convenient size for handling and carried by conveyors to the storage or aging bins to go through a sweating process lasting from two or three days to a month. The time will depend on the nature of the material in hand. Some clays will slake in one-tenth the time of others. Some will never slake at all, and for such nothing but severe grinding treatment can be done.

It cannot be denied that aging clay increases the cost of production if the process stops with placing the ware on the drying racks, but if the per cent. of the perfect tiles brought out of the kilns is increased by aging, then the work is justifiable.

Among the foreign manufacturers, especially the Germans, the aging of clay is considered important. Nearly every plant has its "sumps," or damp cellar. The cost of labor does not stand so much in the way there as with our manufacturers, but where the European nations have cheaper labor with which to do their work, the American manufacturer has the advantage in more readily securing mechanical assistance. Such assistance could be secured in cheapening the cost of aging roofing tile clays.

Ordinarily, the German roofing tile manufacturer will elevate his clay by inclined track to the second or third story of his building, from whence it passes through sets of rolls, one after another, until it lands either on the ground floor or basement, where it is packed away in brick rooms or bins. After remaining in these "sumps" the proper length of time, it is spaded out into small cars, elevated a second time to the upper stories of the building to again pass through rolls and pug mills before entering the final machinery for shaping.

It is not at all improbable that in this exhaustive treatment lies the secret of the durability of the porous tile of the foreign countries. The average Anerican roofing tile manufacturer would say at once that he could not afford to handle and rehandle his clay as his German neighbor does; but if it pays the German, with his low selling price for tile, it would unquestionably prove equally profitable in this country, where better prices are received. The extra money spent to age and better prepare the clay would be more than offset by the fact that it would be found unnecessary to burn the tile so hard to make them frost-proof. The majority of American roofing tile plants are burning their tile to such a high degree of vitrification that great loss occurs in the kiln. Whether this is necessary or not, it is certain that shale clays, especially the harder ones, have often given trouble from frost if not burnt until practically vitreous. It is believed that should these same shale clays be better prepared, complete vitrification would not be found necessary to produce ware of good resisting qualities.

Observations on the arrangements for aging the clay in the various American roofing tile plants showed them to be generally very meager, and inadequate. Usually, nothing more was done than to pile up stacks of clay in the vicinity of the pug mill. In a few cases some burlap was thrown over the top of the pile and wetted down from time to time, but most often the clay was unprotected, and dust from the dry pan was found settling on the surface, assisting to absorb the water from the rapidly drying surface.

To carry out aging properly, cellars or chambers should be provided, into which the clay can be delivered by belt. These chambers should be shut up or made reasonably tight, and water should be available for wetting down the floors, walls and clay coverings from time to time in order to keep the air saturated at all times. This would permit the clay to retain its moisture rather than giving it up to the air.

Without question, the best tempering of clay in this country for roofing tiles was seen at the plant of the Ludowici-Celadon Company, at Ludowici, Ga. The method employed at this plant has in part been discussed elsewhere, but will be restated. The clay, upon being dumped from the bank cars into a hopper, is fed through a pair of large rolls, which squeeze and crush the lumps. It then passes into the combined pug-mill auger-machine of the J. D. Fate Company, where it is thor-

oughly mixed and worked by the double pugging arrangement before being passed into the auger, where it is compressed and expressed in column form, like the bar used in side-cut brick making. This bar is cut into blocks of convenient size for handling, which are carried by conveyors to open-top storage bins where the blocks are unloaded by hand and packed tightly in the bins. It remains here a week, and is

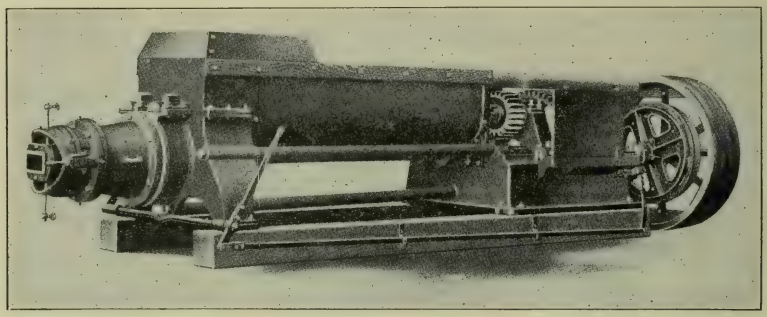

Fig. 65—Combined Pug Mill and Auger Machine, as built by the J. D. Fate Co.

then spaded out, loaded onto a second conveyor, which takes it to another pair of rolls similar to the first except that they are set nearer together. The clay exudes from this second set of rolls in very thin sheets, being scarcely thicker than blotting paper. From these rolls the clay falls into a second Fate combined pug-mill and auger-machine, where it is thoroughly reworked and expressed in blank forms ready to be fed into the roofing tile presses.

It should be borne in mind that the above treatment is given to an unconsolidated clay that is by nature extremely plastic. The preparation given it is not to develop more plasticity, but to bring the clay to its best condition for density and for toughness and for flowing through dies—in short, to make the soundest, solidest tiles possible.

If this company finds it justifiable to prepare a plastic alluvial clay in this exceedingly thorough manner, it should prove a fruitful topic for thought with some of the other manufacturers who are making tiles from comparatively plastic shales.

Scumming or Efflorescence of Roofing Tile Clays.—It is well known that many roofing tiles develop a scum, or white efflorescence, either in the drying or the burning, and occasionally after they are placed in position on the roof.

This scum, or efflorescence, is due to the presence of salts in the clay, shown by repeated chemical analysis to be chiefly the sulphates of lime and magnesia, and less frequently sulphates of iron alumina and the alkalies. Other salts, such as chlorides, nitrates or organic acid salts, may also be present and form scums.

Nearly all common clays and shales contain or have contained sulphur in the form of iron pyrites, and frequently in addition the carbonate of lime and magnesia.

When a clay containing the above minerals is exposed to the action of the air and moisture, the pyrites oxidizes to sulphate of iron and free sulphuric acid. The sulphate of iron, and especially the sulphuric acid, reacts with any of the carbonate minerals that may be present, forming sulphates, like gypsum, epsom salts, etc. Also, other minerals are likely to be decomposed, though less readily than carbonates, yielding salts of alumina, the alkalies, etc. If the clay has not been exposed to the action of the air—that is, not weathered—the pyrites is likely to remain unoxidized during working, and hence relatively harmless, though still undesirable. The other minerals will, therefore, probably remain innocuous, though some clays contain already in themselves water-soluble minerals like gypsum, already formed when the clay was laid down. Such clays are usually too impure to work, and hence do not come into serious consideration. Carbonate of lime or magnesium may be present in large quantities; sometimes in glacial and alluvial clays they may be present in large fragments or as gravel. These carbonates are not easily soluble in pure water. They do not give so much trouble, but with carbonated water they are more soluble. In wares of thin section, like roofing tiles, these carbonates may be changed to sulphates by the action of the sulphur gases of the kilns. Unless the tiles be so hard burned or vitrified as to prevent water absorption, it may be found that after they are on the roof they will show signs of whitewash, due to the rainwater soaking into them and dissolving out these sulphates and then depositing them on the tile's surface as the water evaporates.

The soft, or bituminous, coal used for burning contains sulphur in the form of iron pyrites as well as organic sulphur compounds. When such coals are burned, the iron sulphide gives off gaseous sulphur dioxide or trioxide. These gases pass through the kiln, combining with any water or moisture to form sulphurous or sulphuric acids, which, as stated above, readily forms sulphates from the carbonates.

It is for this reason that often when tile are set wet they will come from the kiln coated with white. The damp tiles very easily absorb the sulphur gases, forming acids, which in turn form soluble salts or dissolve materials not otherwise soluble, and then, as the heat increases, the acid is driven off, leaving the dissolved salts behind on the surface of the tile.

There is still another source from which efflorescence may arise, viz., the water used for tempering. Water taken from wells and streams is more or less impregnated with salts dissolved in it. These salts are usually the bicarbonates of lime and magnesium, and also the sulphates of the same bases. If in large enough amounts, these salts will cause

whitewash, the same as though they had originally been in the clay. Salts may also be obtained from the mortar used in bedding the tiles, though this is not a common thing in the American system of laying.

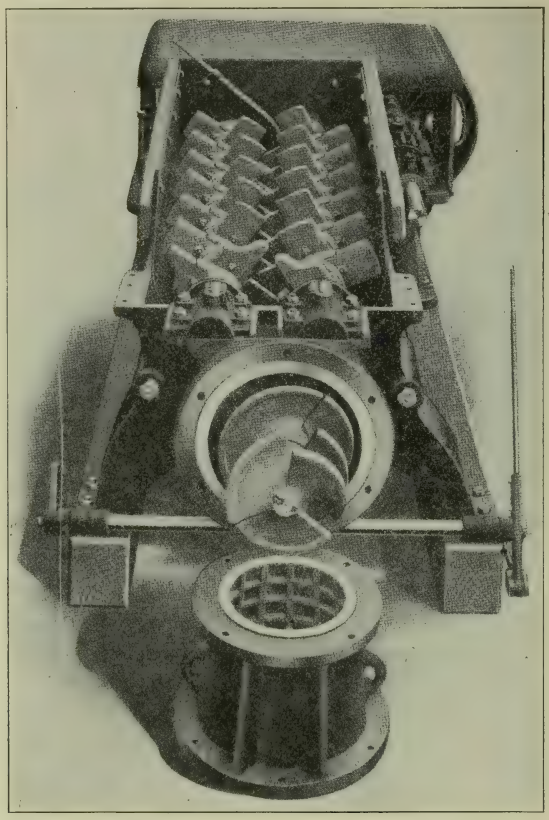

Fig. 65-A—Combined Double-Shaft Pug Mill and Auger Machine.

Prevention of Efflorescence. — To cure a disease it is necessary to remove the cause, and the same principle applies to efflorescence.

In the latter case, we can apply the following methods:

First. Free the clay entirely from soluble salts, by washing it thoroughly. This is theoretically possible, but practically is too expensive. Water of sufficient purity is seldom attainable.

Second. Use the clay straight from the pit before the salts have a chance to form through the influence of weathering of iron pyrites. This is generally feasible, though disadvantageous in other respects.

Third. Prevent the formation of the salts by rapid drying and water smoking.

Fourth. Avoid sulphury fuels for drying or burning.

Fifth. Change the soluble salts to insoluble ones by chemical additions to the clay or the water.

Sixth. Paint the surface of wares with tar, or some similar agent, which will not evaporate or soak in, but will drive the water to escape from the untreated portion of the surface. When the tar burns off later, no scum is found where it was.

Seventh. Application of a coating which on drying peels off in flakes, carrying the collected salts with it. This method has never been used in this country, but was patented in Germany about eight years ago.

Taking up the first method, that of washing the clay or weathering it. The white-washing salts are all soluble or can be made so by weathering. The action though, is slow, and to be properly done, the clay must be spread in thin layers upon a sloping floor, either natural or prepared, so that as the rains wash through the clay dissolving the salts they may be drained away. Otherwise salts will accumulate in concentrated form at the bottom of the weathering pile. This method requires the rehandling of the clay, and as the work to be well done must be extended over a long period of time, it becomes necessary to have extensive weathering areas or floors. Hence in a practical way, this method is too expensive and should not be considered.

The second method. While extensive weathering will prevent white wash, a short period of weathering is very likely to cause the same in a clay that might otherwise be free. As stated before, the sulphates which are soluble are chiefly the results of the weathering of iron pyrites. Hence by working a clay containing pyrites, into ware as quickly as possible, it is often possible to prevent these salts from being formed.

The third method, that of rapid drying and burning, depends largely on getting the tempering water out of the tiles as speedily as possible. Just why the same quantity of water will cause a scum on the surface of a clay if evaporated slowly, in a steamy atmosphere, and will not if the drying be pushed vigorously, is not yet fully understood. It is an unquestionable fact nevertheless. The clay seems to act like a filter, holding back the salts in quick drying, but if time is permitted, they work through the filter and reach the outside at last. It is unquestionably largely due to causes *two* and *three*, that many of the roofing tile plants are troubled with scum at certain times and not at others. Especially is this so in the winter months, when the drying is more likely to proceed slower than during the summer. Also it is usual to draw the material largely from storage piles which have been air weathering from the previous summer, and this air weathered clay often causes scumming, which is avoided when working direct from the pit.

Fifth method. This method is the one most universally used, not only in the roofing tile plants, but in all other branches of the clay industries. Without going into detail as to the various agents that

might be used for the above reaction, it will suffice to say that the compound used must necessarily be cheap and easily handled. So far, some salts of the element barium have been found the most effective, especially the carbonate and chloride. More often the former is used.

When either of these salts is added to a clay containing soluble sulphates, one of the following reactions takes place.

$$Ba\ CO_3 + Ca\ SO_4 = Ba\ SO_4 + Ca\ CO_3$$
$$Ba\ Cl_2 + Ca\ SO_4 = Ba\ SO_4 + Ca\ Cl_2$$

Thus, barium sulphate is formed in either case, which is one of the most insoluble compounds known. Hence, when the calcium or magnesium sulphates have been acted upon by the barium carbonate two insoluble compounds are formed, both inert to the action of the tempering water or kiln gases. No scum can form, as nothing remains soluble. Barium carbonate in itself is only slightly soluble. In order to get it to react with the sulphates, it is necessary to have the two in actual contact. The problem thus arises how to best accomplish this end. In most plants, it is customary to add the barium at the wet pan or pug mill, at the time the water is added for tempering. For some clays low in soluble salts this method will do, but frequently with pug mill treatment it is not sufficient. In some plants they add the barium at the dry pan, thus getting a better mixture. In others, large blunging tanks into which the tempering water and barium are added are provided for, and the latter is kept in suspension by revolving paddles. The barium introduced in suspension in the tempering water is more apt to become closely in touch with the sulphates than if added dry.

While the chloride of barium is easily soluble, its use is not to be recommended, because any excess above that required to counteract the sulphates may be drawn to the surface and itself form a scum by the evaporating water. Also, the product of its reaction with lime salts is chloride of calcium, which is very soluble, and forms a scum, though not so permanent or troublesome a one as the sulphates. Then too, any soluble form of barium is an active poison, so that the use of the chloride should be attended with much care.

By weight, 172 parts of calcium sulphate requires 197 parts of barium carbonate, or in other words, for 1 part of the sulphate it will require 1.15 parts of the barium carbonate to counteract it.

Taking for example, a clay containing 0.1 per cent. calcium sulphate. Owing to inability to get the barium evenly distributed throughout the mass of clay, it has been found from experience, that there should be added a large excess over the theoretical quantity, in the neighborhood of ten times as much barium carbonate as is theoretically required. Thus with barium carbonate costing two and one-half cents per pound, and a clay containing 0.1 per cent. calcium sul-

phate, there would be required for a square of tiles, weighing 1,000 pounds, approximately twelve pounds of barium, costing thirty cents. While this would be an added expense, its use would not be prohibitory.

It very frequently happens that the large hand-made ware about a roofing tile plant is the only class that gives trouble from white wash. In the light of what has been written in the last few pages, it will be easy to understand why this is so. The tile made by machinery passes directly into the dryer and is very quickly dried, while the thick, heavy ware made by hand is allowed to stand for days, in order to dry slowly. Then upon going to the kiln, it is much more likely to be damp than the tiles. So that the slow drying combined with the possible kiln dampness is very apt to promote the formation of soluble salts in and on the hand-made ware, where the regular tile will escape it.

It has been the custom in a few of our plants, and more frequently in the old world, to coat or paint the newly made terra cotta pieces with tar or oil, on the exposed or face side. This coating of tar or oil will cause the water that is in the piece to evaporate from the inner or opposite side, thus depositing the greater part of the salts where they will not be objectionable. Any salts that have formed under the tar or oil, will very likely be broken up or reduced as the tar burns off, liberating the sulphur which passes off with the kiln gases. This method of preventing scum on special made pieces was used by the writer in 1899 with remarkable success.

There is also a custom among a very few plants at the present time to add a small per cent. of black oxide of manganese with the barium carbonate, it being claimed by those using this method that the manganese helps very materially in preventing the scum. It is possible that the manganese acts favorably in hiding the scum. At least, where used it was impossible to find a white washed tile. But no chemical ground for this practice can be discovered, and it is probably unnecessary and without result.

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CHAPTER V.

THE MANUFACTURE OR FORMING OF ROOFING TILE.

In the preceding chapters, the selection of the clay and its preparation in the form of a stiff mud or plastic paste have been discussed. The fashioning of this plastic paste into the various simple and complicated shapes found in the roofing tile industry forms the subject of this chapter.

As in the manufacture of nearly all other clay products, there are a number of different methods of attaining approximately the same end, and also, the same method may be applied to producing a variety of different products. Exact classification is therefore difficult.

MECHANICAL APPARATUS FOR ROOFING TILE MANUFACTURE.

Roofing tiles are produced by at least four different methods:

First—By exclusively hand molding. This is the simple archaic process which has originated in every part of the world when the use of roofing tile was first attempted. It is not to be considered as a serious manufacturing method to-day, especially in this country. It can still be found in use, however, in Mexico and many countries where labor is cheap and ignorant and machinery expensive.

Second—By use of a hand power press or machine.

Third—By use of a mechanically driven power press.

Fourth—By forcing out the clay through a die of proper cross section, and cutting up the resultant column or bar into tiles of proper length.

Neglecting the small and unimportant output made by hand or by hand presses, we may say that the roofing tiles of to-day, in America at least, are made either by the fourth or a combination of the fourth and third methods given above. The fourth method is applicable to the production as finished tiles only of simple forms of the shingle, Spanish and interlocking patterns. The true interlocking tiles cannot be made by this method. As they are the most important varieties of roofing tiles, it follows that the combination method of manufacture, by forming the clay into clots or blanks, of the proper size, shape and weight by means of the flow die process, followed by their pressing into finished roofing tiles by some form of power press, is the most common and must important process of manufacture to-day. There are, therefore, two important types of machinery to consider: viz. first, the flow die machines, which may produce a finished product by themselves

alone, but are most widely used as preparatory machines to form blanks; and second, the power presses, which cannot economically be employed except when fed with prepared blanks, but which are necessary as the final step in all but the simplest forms or designs of roofing tiles.

FLOW DIE MACHINES.

Whenever plastic clay is subjected to pressure, it tends to obey the laws of a fluid, by transmitting its pressure equally to all parts of the mass, and by escaping by flow, through any and all orifices which may be accessible. Plastic clay is far from being a perfect fluid, but under high pressures it is capable of flowing very much like a fluid would, and through very small aperatures. Whenever the pressure ceases the parallel also ceases, for the erstwhile fluid at once stiffens to a more or less solid mass, retaining the form received during its period of flow.

There are two types of flow-die machines, differing in the mode of applying the pressure to the clay: first, the plunger or piston machines, and second, screw or auger machines. The former comprise several varieties, while the latter are to a much larger degree true to one single type.

Plunger or Piston Machines.—There are several types of these machines. The direct acting, where a piston is made to press the clay ahead of it, by means of steam, compressed air, or water or oil under pressure, and the indirect, where the piston is actuated by some form of mechanical gearing, cams, cranks, levers, screws, etc. These various devices have been evolved in connection with the sewer pipe and brick industry chiefly, and only one plunger machine was found in use in the American roofing tile plants. This was at the works of the Cincinnati Roofing Tile and Terra Cotta Co., at Winton Place near Cincinnati. In this machine, the clay is pushed out by a movable head or piston working back and forth in a rectangular chamber. The head is moved by an eccentric or crank shaft and connecting rod.

On the back stroke, or as the head is drawn back to its stopping point, an opening into the clay chamber is disclosed. Into this opening a quantity of clay is fed, and as the plunger head comes forward it pushes the clay ahead of it. After a sufficient amount has been added to fill the front of the chamber, the clay will be seen to issue from the die in spurts, corresponding to each forward movement of the plunger. Naturally the flow cannot be continuous, as in the case of the screw or auger machine, but is always intermittent in a reciprocating machine. The length of flow—or, in other words, the distance that the column will issue from the die at a stroke—will depend on the amount of clay fed into the machine at each stroke by the feeder. It is only natural to expect the results from a mechanically geared plunger machine to be variable and unsatisfactory. After each stroke of the plunger the issue comes to a full stop. Then, as the new charge packs, consolidates

and comes forward, the column shoots out of the die at a high speed, diminishing as the plunger reaches the most forward point in its stroke. The irregular speed means that the clay has very little time to adjust itself to the conditions existing in the die. Then, further, there is always more or less wastage, due to the fact that the feeder is unable to adjust the feeding so that an equal length is issued each time. Hence, in order to be sure to have sufficient clay bar issue to make the proper length for a tile, the extra clay must be added each time. This extra material is cut off as waste, and must be rehandled to get it back to the machine again. The difficulty of regular feeding and the ill effects of irregular feeding are both apparent. It would seem as if some preliminary machine to pack the clay into a compact mass, of which a uniform quantity could be fed with each stroke, would materially help the performance of the geared plunger machine.

In this connection a small auger machine, through which the clay could be run in a continuous column, has been suggested. By means of a simple cutter, this column could be cut into lengths which would contain just the necessary amount of clay for each tile. By having the auger and cutter located above the plunger, it would be possible to so speed them that the feed would be automatic.

However, if the auger machine were added, it would prove better to dispense with the plunger machine, and run the tile on the auger machine direct. As before stated, the plunger machine has many disadvantages which are largely overcome by the use of an auger machine. Another handicap of the geared plunger machine is that it is speeded to give a definite, limited number of strokes per day. Every time a useless stroke is made, or the tile is spoiled, just that number will be cut from the day's output. For instance, all of the clay cannot be expressed at each stroke; in fact, a large amount is retained in the head of the machine to act as a cushion. This excess clay will become too dry or hard, which necessitates the removal of the head plate of the machine two or three times a day, and pushing the great lump of hardened clay out, to be returned to the tempering machine. Much time is lost in this way, or, in other words, many strokes of the piston, each of which should produce a tile, are lost. Other interruptions also intervene in the same way. Further, the plunger machine has a fault characteristic of itself in that it entraps air into the bar of clay more than any other type of machine. The piston, coming forward, closes the feeding opening, and compresses the clay so quickly that but a part of the air is able to escape. This entrapped air may escape in part around the plunger head, but what cannot escape in that way must pass out with the clay bar. It may show as blisters on the tiles, or may produce laminations or open cavities inside the bar. In the case of hard-burned tiles it is not likely that these laminations will give trouble; but should

the tiles be under- or soft-burned, then water may accumulate in these open spaces and freeze, and the tile will then surely go to pieces.

With the intermittent flow of clay from the plunger machine, it is not necessary to use a reel or continuous cutter. A simple hand cutter is all that is necessary, as there is time to cut the tile and remove it during the return of the piston to its starting point. This cut-off is simple and easy to operate.

About the only thing that can be said in favor of the plunger machine is that it allows the cutting and offbearing of the tile to be accomplished with more care than when using the trowel method for the removal of the product of a continuously moving bar. The average output of this plunger machine at this plant is about 4,500 tile per day, as against 10,000 to 12,000 by the use of an auger machine, employing the same number of men in each case. This shows that the additional time for handling must be considerable.

The use of this geared plunger machine, with its limited number of strokes per day and its small output per stroke, is by no means the best that could be done. The direct-acting plunger machines, using steam cylinders as the motive power, are very much more efficient in sewer pipe, brick and hollow tile manufacture, and can handle large tonnages per day. Their gain lies not only in the larger capacity of the cylinders, but in the delicately controlled power by which the flow can be regulated to a nicety. The last clay in the cylinder can be expelled at substantially the same rate as the first, and as fast or as slow as is desired. By cutting several tiles at one stroke, the proportion of waste could be very materially reduced. In fact, the Cincinnati machine represents about the low-water mark of plunger machinery operation.

The faults of bar structure and the intermittent nature of the flow, however, are matters that cannot be overcome by any plunger machine.

Screw or Auger Machines.—The general principles of the auger machine are well known, and require no extended description. Essentially it consists of a barrel, usually horizontal, and either cylindrical or conical in shape, through which runs a center shaft, which carries a series of cast or forged sections which combine to make a more or less complete screw. The clay is fed into the rear of this barrel, and is carried forward by the screw, and forced out of a more or less constricted die in the front in the form of a continuously flowing bar or column of clay.

The different makes of auger machines have naturally played almost all possible variations on the different features of the auger machine. For instance, the shape of the barrel varies from a pure cylinder to a pure cone, or combined part cylinder and part cone, and in some cases they are of oval or elliptical cross-section. The frame varies from cast iron to structural steel. The driving may be done by single gears, double, or even triple gears, with ratios ranging from four to one up to twenty to one. The driving mechanisms include belts, which are the

important method; direct connections to shafts by gearing; electrical drive; and rope drive. The auger shaft may be cast or forged. It may be equipped with a complete screw slipping on in sections, or it may be a series of forged knives or blades, set so as to collectively form a highly interrupted screw. The thrust block or bearing at the rear of the auger shaft is like the step of the dry pan, the point where trouble is first likely to manifest itself. The enormous forcing power of the whole machine is concentrated on this one point, and heating is very sudden if the lubrication is imperfect or the alignment of the end plates gets disarranged. Auger machines also vary enormously in size, from giants able to force out five hundred tons of clay through a two and one-half inch by four inch nozzle in ten hours, down to toy sizes that will scarcely make ten tons of ware.

Auger machines have been developed most extensively with an eye to the brick industry. Their use in producing hollow goods of all sorts and roofing tiles is distinctly of secondary importance. Hence we find the auger machines used in the roofing tile industry are usually the smallest sizes of brick machines equipped with the dies. Only a few auger machines have been developed especially for roofing tile purposes.

The critical features of the auger machine are: First, the auger for forcing the clay out; second, the die, through which it is forced. All other parts of the machine may be built in various ways without specially affecting either the power required to drive the machine, the quantity or quality of the output. They may, of course, affect the size, weight, frequency of breakdown, ease of access for repair, etc., but they are not essential points.

The auger, or screw, as before stated, may be made in sections to slip on the auger shaft, one after the other. In some cases the fittings are merely blades set with a slight spiral twist, and forming a slightly interrupted screw, and sometimes they are a set of steel-forged knives set at a variable lead at different points on the shaft. However, in all cases the effect secured is that of a screw.

The front end of the auger shaft is fitted with a casting having a spiral thread of large pitch, making one or more complete turns around the core, or axis. This casting is called the auger. It is designed to gather up and compress the clay delivered to it by the segmental screw made by the knives or blades farther back on the shaft. While the clay is being compressed it is being pushed forward to the die, through which it passes under much pressure, taking its final shape as it comes out.

The auger may be made up of a single spiral, in which case it is necessary to have a spacer or collecting chamber placed between the end of the auger and the back end of the die. This is necessitated by the clay coming from the auger in a single stream, which follows the turns of the auger about the die entrance. Should the auger and die be placed too close together, it would be found that the column of

clay issuing would not flow regularly and true, but would wabble or lunge from side to side as the opening in the auger passed from side to side. By putting in the spacer and making a collecting chamber, it will be found that the unequal or irregular pressure of the auger is overcome in part or completely. The character of the clay as to slipperiness, and the necessity for the product to be sound or devoid of structure marks, will determine whether this type of auger is suitable or not in any given case.

For instance, in Chicago common brick yards, a single-threaded auger of large pitch is used, and enormous quantities of brick are made per day from a fat, sticky, slippery clay. The structure is very bad indeed, the bar being composed of spirally disposed layers, separated by laminations or unbonded zones. For the purposes in view this bar structure is a matter of indifference, and quality and smoothness of exterior are the only criteria.

For a paving brick plant such a course would be out of the question, for a bar as nearly devoid of laminations or spiral structure as possible is here necessary.

In these cases augers are made with two threads, or "double bitted." This style of auger overcomes to a large extent the trouble of the single-thread type in that the clay is delivered to the die in two streams, which blend into one another and make a more regular and uniform feed. In the manufacture of brick it is rarely necessary to go beyond the double-threaded auger to get a bar of even flow and good structure, at least with the intervention of a collecting chamber.

In some brick clays a poor structure results even with a double-threaded auger and intermediate collecting chamber between the front of the auger and the back end of the die. The length of this chamber is of great importance. It must be determined by experiment in each case. The correct distance is manifested, when found, by a greatly improved structure of bar.

In some cases, chiefly for products like shingle tiles, drain tiles, or bars of small cross-section and hence of exaggerated tendency to laminations, augers of three threads are employed. They look almost like the propellor of a steamship. The three streams of clay, blending into one, do away with uneven or convulsive flow to a very complete degree. The clay is delivered to the die in a steady, continuous feed, with equal pressure over the entire area of the die at all times. It is thought that a short collecting chamber, even with a three-wing auger, would be advisable, though at the United States Roofing Tile Company they use none, and the distance from auger to die is only two inches, and a bar of good structure is obtained.

Should a single-wing auger be used for roofing tile, it should be provided with a lip, or projecting flange, along the edge to prevent the clay from slipping or working back while under pressure. The collecting

chamber should be long—say twelve or fifteen inches. This will permit of the equalization of the flow and break up the laminations in part, but at the same time it will require a great deal more power to operate the machine.

The auger, assisted by the more or less interrupted screw behind it on the auger shaft, constitutes the propelling force of the machine. The die is the shaping mechanism, which forms the clay into a bar of the desired cross-section. A flow-die is simply a tube through which the stream of clay flows. It limits the shape or cross-section of the clay bar on two axes; the third axis, being the line of flow, is indefinite and unlimited.

The nature of this tube is, however, a matter of the gravest concern for on it depends the smoothness or surface perfection of the clay product. If the tube is perfectly straight—that is, of the same dimensions from end to end—the bar would be of bad structure and the power required to operate it would be enormous. If the tube be conical, with a larger area in the rear next the auger, and a reduced cross-section, the clay will feed into it better and less power will be used. But if the nozzle is the smallest point in the tube, the bar would tend to ruffle, or flow with a rough, cracked or scarred exterior. The usual plan is to combine a conical or sloping cross-section for the rear half or two-thirds, with an almost if not quite uniform cross-section in the front portion.

The bar thus formed in the rear of the die compresses and elongates as it slips forward and in the front portion is "slicked up," or smoothed for its final surface.

The variations in dies are innumerable. Only a few will be discussed here, and those chiefly in connection with the plants or machines in which they were observed.

The following auger machines were observed in use in the roofing tile plants of the country:

The Murray Machine.—This machine is the most largely used in the manufacture of shingle tiles. It was designed by Mr. A. H. Murray, of Cloverport, Ky. Its pugging chamber is short, and situated a little above and attached to the case containing the auger. The auger and die are the important part.

This machine is simply a small combined pug mill and auger machine. The pugging chamber is not over four feet long, the auger case and die possibly two feet more. It is only about four feet high. When these figures are compared with those of the ordinary sizes of combined pug mill and auger machines, it will be seen that it is very small indeed. The clay has to be prepared by other pugging or tempering machinery before being fed to the Murray machine. In the Murray machine the die is made to act as a collecting chamber and a die at the same time.

Four plants were found to be using the Murray machine. The Huntington Roofing Tile Company, two machines; the Murray Roofing

Tile Company, one machine; the Ludowici-Celadon Company, at Chicago Heights, Ills., one machine, and the same company, Ludowici, Ga., one machine. While this machine is small, its output is equal to that of the larger machines, averaging daily about 12,000 shingle tiles. The main difference, however, lies in the fact that the clay must be run somewhat softer than it is in the larger machines. This point is not a serious objection, except that a higher shrinkage of the tile is likely to be encountered, and this high shrinkage is very apt to produce a larger per cent. of twisted tile.

The combined pug mill auger machine made by the J. D. Fate Company, of Plymouth, Ohio, is apparently very popular among the roofing tile manufacturers. Not less than six of these machines were found in use. There were three different sizes, named the "Hummer," the "Premier," and the "Imperial," of which there were two each.

The main reason for the popularity of the Fate auger machine is that the double shaft pugging-part gives the clay a very good mixing or working before it enters the auger. Also, the head of the machine is so arranged that it is very easily opened for cleaning and changing dies. The strength of the machine is such that little trouble has been encountered from break-downs. It is true that other makes of machines on the market meet the same conditions, but so far they have not been able to force their way into use to nearly as large an extent as the Fate machine.

The American Clay Machinery Company, of Bucyrus, has four auger machines in the roofing tile industry, viz., at the New Lexington plant of the Ludowici-Celadon Roofing Tile Company a No. 1 "Giant" and a No. 2 "Giant" at the Alfred plant of the same company, a "Centennial," originally made by the Frey-Sheckler Company (now the American Clay Machinery Company); at the Alfred Clay Company, Alfred, N. Y., a No. 2 "Giant."

The Bonnot Company, of Canton, Ohio, has one auger machine in use in the roofing tile field, viz., at the New Lexington plant of the Ludowici-Celadon Company, where a No. 2 Bonnot is used for shingle tiles, blanks and other work.

Mueller Brothers, 2935 Clark avenue, St. Louis, Mo., make a small auger machine for the roofing tile industry, the distinguishing peculiarity of which is the use of two parallel auger shafts, whose streams unite in one die to produce a single bar of clay. They sell the larger part of their output through the Illinois Supply and Construction Company, of St. Louis. These machines are in use by the Mound City Roofing Tile Company, and the Detroit Roofing Tile Company, and single shaft machines of the Mueller plant are in use in the laboratories of the Ohio State University, at Columbus, the Bureau of Standards, at Pittsburgh, and Edward Orton, Jr., at Columbus. (See figure 19.)

As to the success of these small machines, there is not much to be said, because the companies using them are not working them at all closely to their limit. However, at one of the plants, the objection is raised against them, that the augers will wear unevenly and the feed of the clay into the die then becomes unequal on both sides of the tiles, causing one side of the tiles to run faster than the other. Such tiles, of course, cannot be used on account of the warp or bow given them. These machines are much too light for heavy or continuous work. The clay has to be run much softer than it otherwise would.

It seemingly is somewhat difficult for many people to understand that it takes more power to run roofing tiles through a die than it does ware of larger cross-section, the reason being that the proportion of frictional area in the case of tile is far greater in proportion to the quantity of clay than it is in the case of side-cut brick for instance. Many have thought that because very little clay is used in tile, that it only requires a small, light machine to handle it. Such is far from the case. The auger machine for making roofing tile should be built upon generous lines, with much strength, so that the tiles can be run from stiff clay and put under much pressure in passing through the die. The actual barrel or drum of the auger does not necessarily need to be large, but the auger and its thrust-block should be given much attention. The gearing should be strong and accurately made.

Cutters.—After the clay has been extruded from the die in the form of a continuously moving bar, the question of cutting it up into lengths while in motion is to be overcome. Automatic cutters, moving at the same speed that the bar moves, are produced by practically all manufacturers of auger machinery. These necessarily are adapted, each to some special tile, and for this reason will be discussed in connection with the machine and the plant where they were seen in operation.

A large part of the work of auger machines in the roofing tile plants, is in preparing blanks for subsequent pressing on power presses. This purpose is a much easier one to fill than to make a finished tile by auger machine alone, as poor surface or bad structure may be overlooked, if they do not persist through the subsequent pressing, which they generally do not.

Presses.—The presses used in making roofing tiles may be classified as in the following tables:

Hand Presses	Screw.	
	Toggle.	
Power Presses	Pentagon	Crank.
		Eccentric.
		Toggle.
	Trimmings	Crank.
		Toggle.
	Special.	

The various roofing tile presses used for the making of roofing tiles and tile accessories are in considerable number, and it would almost seem that each plant was trying to solve the problem of making the best tile press for itself. There are in use, at the present time, revolving presses made by seven different companies as follows:

Rogers Machine Tool Company.....Alfred, New York.
American Clay Machinery Company.....Bucyrus, Ohio.
Fisher & Koontz, Machinists.....Parkersburg, West Virginia.
East Iron Machine Company .....Lima, Ohio.
Crawford & McCrimmon Company .....Brazil, Indiana.
Illinois Supply & Construction Co.....St. Louis, Missouri.
Ludowici-Celadon Company.....Chicago, Illinois.

This latter company does not manufacture presses, but for two of their plants they have had presses built for them, from the patterns of a German press largely used by the Ludowici's in France and Germany.

In taking up the study of the revolving power presses as a whole, the first thing observed is that they all have one common feature, i e., the revolving pentagon upon which the dies are placed. The chief differences in the presses are in the methods of applying the pressure, and the shape of the frames of the press.

There are two modes of application of the pressure, first, by crank shaft, cams or eccentrics, and second, by toggle-joint movements.

The presses using crank shafts can again be divided into two classes, first, those in which the entire gearing is attached to the main frame work of the machine, and second, those having a solid base, but with the gearing separate from the main frame work.

Crawford-McCrimmon Press.—This company was undoubtedly the first to manufacture a revolving pentagon press in this country. Their press is of the eccentric type, having the gearing attached to the frame of the press.

As shown by the cut, the press consists of two side frames, connected at the top by a curved yoke. Carried upon the upper part of the frame is a shaft, on which the belt or driving pulley and the fly or balance wheel are placed side by side. This shaft carries a small gear or pinion wheel on the other end which intermeshes with the large gear wheel shown on the right of the press. This latter gear drives the main shaft which extends across the press, carrying the two eccentrics which are connected by two threaded rods each to the cross head or plunger of the machine. The cross head works up and down between guides attached to the side frames of the press. To the under side of the plunger is attached the upper die.

The large gear wheel has fastened to it a stud-bolt, which projects outward. This stud or "trip" as it is called, is so placed that it engages one member of the spider wheel, shown on the right side of the press, below the main gear wheel, at each revolution. Immediately back of the spider, near the frame work, can be seen a wheel or collar in which

pockets are cut. These pockets are to receive the plunger or pin, shown above the lock or pocket wheel. The main shaft to which the spider wheel is attached carries the part of the press called the pentagon, upon

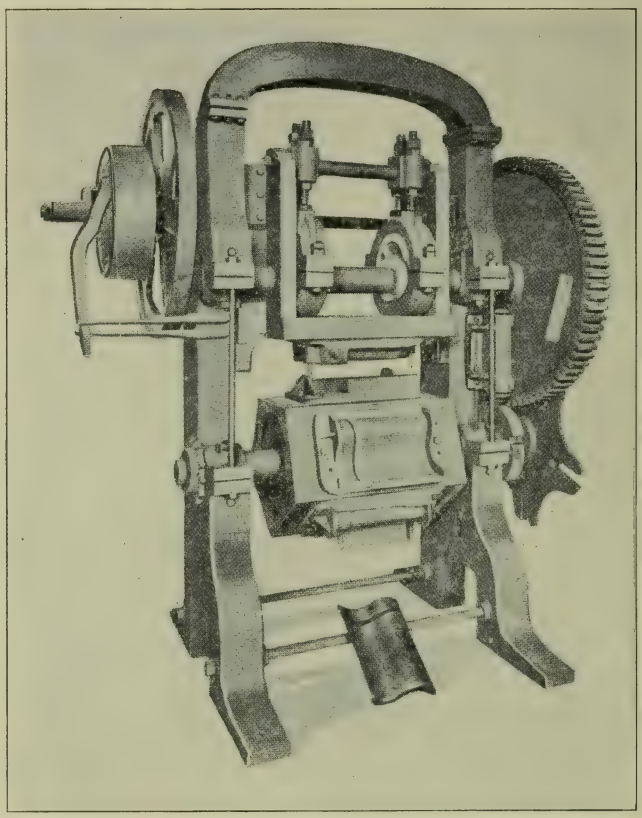

Fig. 66—The Crawford & McCrimmon Roofing Tile Press.

which the lower dies are placed. The operation of the pentagon is actuated by the trip pin engaging the spider wheel as the main gear revolves. At the instant the trip pin engages, the lock pin or plunger, which holds the pentagon firmly while the pressure is being made, is released and the pentagon revolves one-fifth of a revolution. The top die descends, making the pressure, then raises, and the pentagon is tripped, and turned one-fifth of a revolution again, and so on.

While quite a number of these presses have been made and sold by the Crawford & McCrimmon Company from time to time, there was only one in use at the time of the visits made to the various plants of this country.

One objection to this press, and the same applies to all presses of this type, is that the main driving mechanism is attached directly to the press, and too far from the base. In other words, the machine is

top heavy. The constant strain and racking of such a press is far greater than in the type where the power is applied lower down and separate from the frame work.

The Grath Press.—This press is manufactured by the Illinois Supply & Construction Co., at St. Louis, Mo. The main difference in this press over that just described is in the method of applying the pressure to the plunger head.

It will be seen that a crank shaft is used in the place of eccentrics. While the crank shaft may be a better mechanical movement than the eccentric, the manner in which it is used in this case is a disadvantage in as much as the pressure to the plunger is applied at the center. The cross head or plunger must depend entirely upon the guides to hold it true, in case there is an excess of clay at one end of the die over that at the other. While it is true that all presses must depend on the guides to properly center the upper die with the lower one, it is certainly better from a mechanical standpoint to apply the pressure equally at both sides of the plunger, rather than at one point.

This press also differs from the Crawford-McCrimmon press in the matter of locking or holding the pentagon in place for the pressure.

This feature as shown in the cut consists of a raised rib or lug cast on the main gear wheel. This circular rib engages with the spider wheel direct, as shown. At the point where the trip pin is located, a section of the rib is cut away, thus allowing an open space to permit the spider to turn one-fifth of a revolution. There is an objection to this feature, arising from the wearing away of the segmental sections on the spider, allowing the pentagon to have more or less play backward and forward. With dies using trimmers, such conditions cannot be tolerated at all. The pentagon must register exactly with each motion.

It is plainly seen that the wearing surface of the individual segments of the spider is far less than that of the interlocking rim, and will therefore wear away much faster. This could be overcome by making the spider much larger, and the holding rim smaller, or by providing renewable wearing surfaces at the critical points. There was found but one plant using the Grath press, viz., The Detroit Roofing Tile Company.

The Ludowici press made in America from German patterns, is of the same general type as the two types just described, although not built so heavy. This is easy to understand when it is known that the Germans are as a rule using plaster dies and must necessarily work their clays much softer than they would if metal dies were used. They have, therefore, not built presses as heavy as the American firms, who have had to build with a strength to accommodate metal dies and stiff clay.

Presses with Separate Driving Mechanism.—This type of press has the main drive gearing on the same bed plate as the press proper, but not on the same frames, thus relieving the press frame of the overhead load.

In this general type of press are embodied the best mechanical features, and it will without doubt prove to be the press of the future. There were eleven of these presses in use in the various plants at the

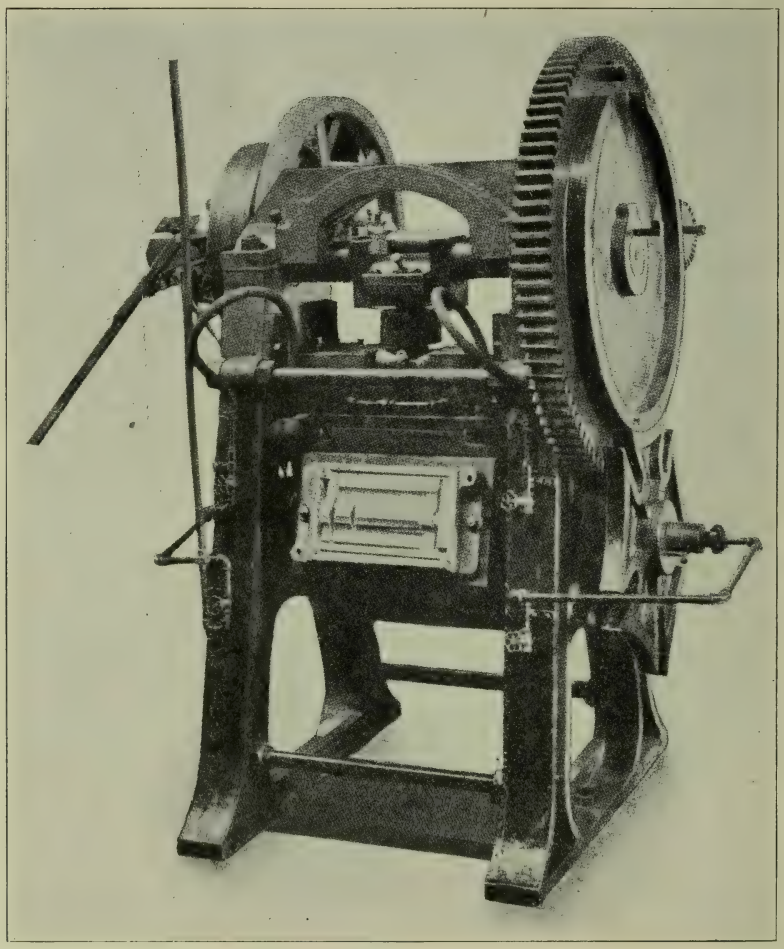

Fig. 67—The Grath Roofing Tile Press.

time of taking the field notes for this report. The eleven presses in use were made by three different firms. Six of them by the Rogers Machine Tool Company, three by the American Clay Machinery Company, and two by Fisher & Koontz.

The Rogers Press.—The Rogers Machine Tool Company has the largest number of presses in use at the present time. They well deserve this credit, for they were the first to produce a machine of distinctly different type from the foreign presses. The following illustration shows one of the early presses developed by this firm, a few of which are still in existence.

This press has been modified and improved until the most recent form put out by this firm has diverged quite widely from the starting point.

It will be observed that this press is constructed upon generous lines. The entire press stands upon a solid bed plate, to which are attached the two heavy upright frames carrying the pentagon and plunger. To the left of the main frame, and on the same bed plate, are the two upright pedestal bearings which carry the primary and secondary driving mechanism. A heavy fly wheel is attached to the primary shaft, which in turn is controlled by means of a friction clutch pulley. The secondary shaft, shown on the top of the pedestals, drives the shaft which carries the eccentric to operate the plunger by means of a small pinion.

It will be observed that the cross head or plunger is very large, having the two side frames with side and back face plates for guides. At the upper right hand corner of the cross head can be seen a gib or take-up. This is used to provide for the slight wear that may occur on the face of the guides.

The spider wheel is made very large, thus affording a large bearing or leverage surface for holding the pentagon steady.

The trip wheel is shown just above the spider, and behind the large upper gear wheel. This trip wheel is provided with a case-hardened steel roller and pin, which enters the slots of the spider wheel and turns it one-fifth of a revolution at each stroke of the pressure head. The capacity of such a press is about 5,000 to 6,000 tiles per day of ten hours, and requires about ten horse power to operate it.

The American Press.—The press of the American Clay Machinery Company is of this same type, very little difference having been made in its design. The main advantage claimed by its manufacturers, is in the manner of making the main housings or frames of the press. In the Rogers press they are cast in one solid piece, while the press in question has the housings cast in two parts each, depending on the strength of two steel rods to each housing to take care of the pressure between the head and pentagon.

Fisher & Koontz Press.—This press is practically the duplicate of the one just shown. Hence a description is unnecessary.

It will be observed from the illustrations of the presses shown, that the true American roofing tile presses are equipped with double back gearing, while the presses of the German type have single gearing only. The double gearing assists the press in the matter of steady, uniform speed. The effect of the pressure is scarcely noticeable at the driving belt.

The Klay Press.—The Klay press is manufactured by the East Iron Machine Co., Lima, Ohio. It was designed and patented in 1901, by

Mr. A. B. Klay, of Lima. In 1908 only two of these presses had been installed, both being in use by the National Roofing Tile Company at Lima.

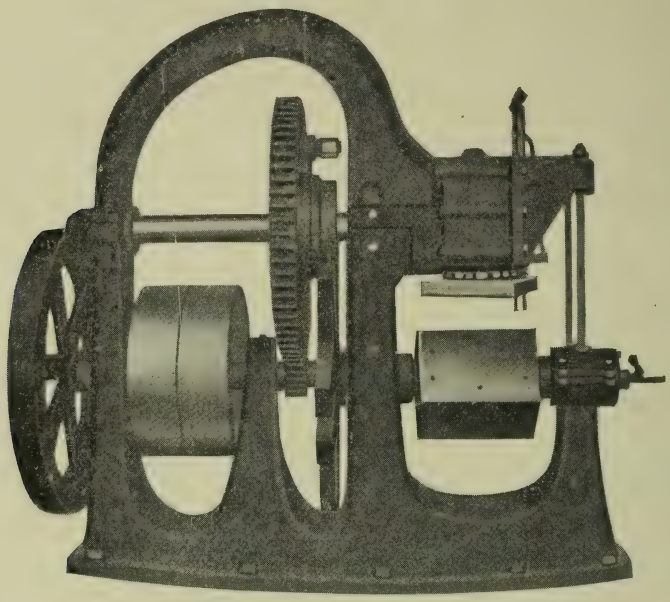

Fig. 68—Early Form of the Rogers Roofing Tile Press.

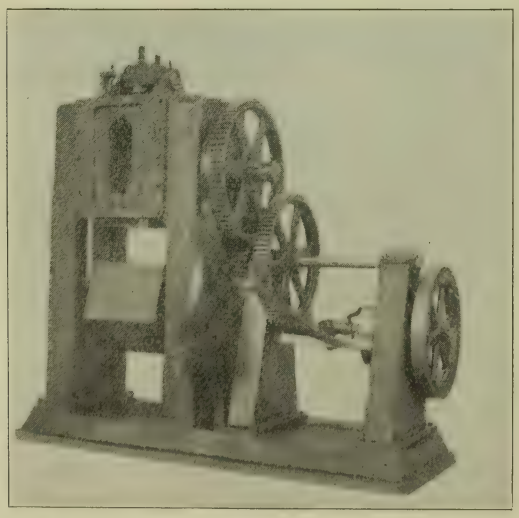

Fig. 69—The Rogers Machine Tool Company's Roofing Tile Press.

The Klay press differs very widely from all other makes in the matter of applying the pressure to the plunger head by toggle joints instead of the crank or eccentric.

It will be seen from the cut that the press stands upon a cast bed plate, upon which are erected the two tall housings on the right and the pedestal bearing on the left.

It will be observed that the machine is belt-driven. The main driving shaft carried a pinion which engages the gear wheel shown to the left side. This gear in turn is attached to a shaft carrying two pinions which work against two large gear wheels shown below. These large gear wheels are made with cams which in turn operate the plunger shown just above the cam gear wheels. The plunger, it will be seen, is attached to, and operates the toggle joint just above it. This toggle in turn is connected to the main toggles which operate the plunger head. Thus with all of the compound movements, an enormous pressure is exerted at the pentagon. The pentagon is operated by a small sprocket or trip wheel which meshes with a segmented one on the cam shaft.

It will be noticed that there is a double set of toggles at the plunger. The inner or large ones operate the plunger, and give the pressure, while the smaller or outside ones operate the frame around the upper die, called a trimmer. These latter toggles are made a little longer than the main ones, so that as the plunger descends, the trimmer moves down a little faster and farther than the plunger-head. By so doing, it reaches and encloses the lower die before the pressure is applied. Thus the clay is held securely in by the trimmer so that when the pressure is released the tile is left with perfectly smooth edges, requiring no trimming. The dies on this press are made of "white metal," and heat must be supplied to make the clay release. This is supplied at the upper die only, steam being used. The hose pipe shown in the cut, which enters between the toggles, conveys the steam into the hollow backing of the upper die. A small pipe can be seen extending across the front of the upper die on the pentagon. At the bottom is another, and one in the back is placed so that it is in proper line for the upper die. These small pipes are for spraying oil upon the dies by means of compressed air. This pipe system is so connected with a trip that it automatically sprays the oil at the proper time when the plunger is up, thus doing away with the bothersome and expensive hand method of applying the oil.

While this press has had but little opportunity to demonstrate its working qualities, outside of this one plant, it was claimed by those using it, that it had given very good satisfaction there. The press, however, is very much more expensive than the other types of presses built in this country. The ordinary presses cost from $800.00 to $1,500.00, while the Klay press runs very much higher.

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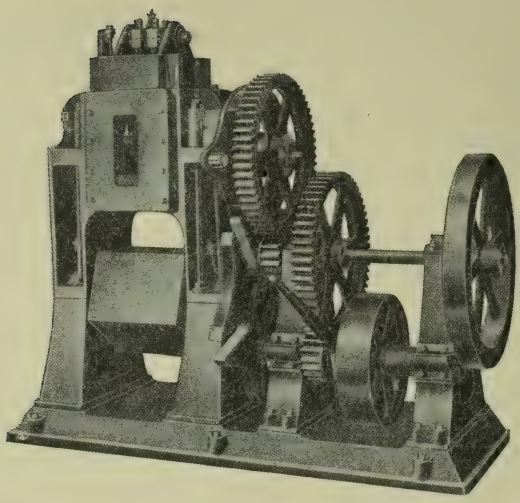

Fig. 70—The American Clay Machinery Company's Roofing **Tile Press.**

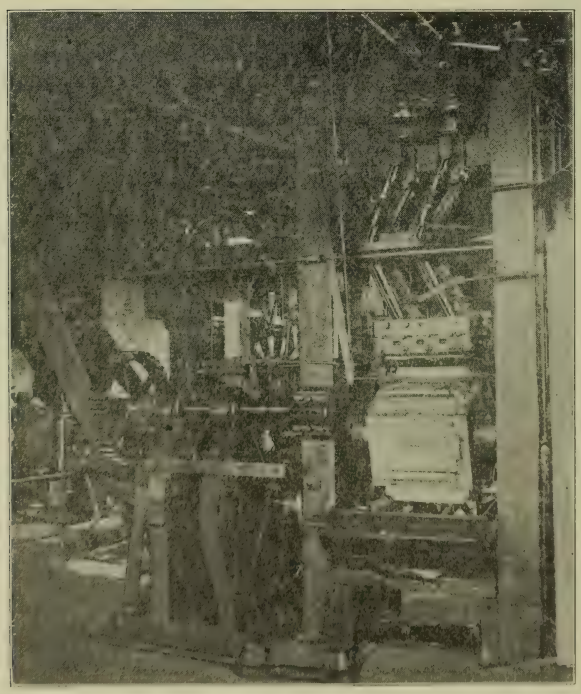

Fig. 71—The Klay Roofing Tile Press. (National Works, Lima, O.)

SPECIAL OR TRIMMINGS PRESSES.

These presses differ from the pentagon presses in that they are usually made to carry one die only. Their use is for the special pieces that must be used with the regular tiles to make a roof complete. They produce such shapes as eave tiles, top or ridge tiles, hip rolls, crestings, etc.

The press used for this purpose differs quite widely in the method of applying the power. Five machine firms were represented by presses manufactured in this country, while a press manufactured in Germany has found use with one American company.

The American firms were as follows:

The C. W. Raymond Company	Dayton, Ohio.
Illinois Supply & Construction Co	St. Louis, Missouri.
Rogers Machine Tool Company	Alfred, New York.
American Clay Machinery Company	Bucyrus, Ohio.
East Iron Machine Company	Lima, Ohio.

With the exception of the Raymond press, these presses are all power driven. In the selection of a trimmings press, much care should be used, output and ease of operation being the primary objects of attention.

In the foreign countries, screw trimmings presses have been very widely used in the roofing tile industry, but in our own country the screw press has found but little or no use in this industry. There are hundreds of screw presses in use in the dry press tile factories, making wall and floor tiles, but for plastic clay they are not popular. The American manufacturer wants a press that can be operated more quickly than a screw press.

The Raymond Hand Press.—This hand press has found the greatest use in this country of any hand-power press. It is known as the "Perfection Hand Press." It is made in three sizes, the No. 3 size being the one most in use. (See Figure No. 120.)

It will be seen that the press is of the toggle joint type, the pressure being exerted by bringing the toggles to a vertical position, which is accomplished by pulling the hand lever down. This press when properly arranged, has a sliding track arrangement, whereby the tile dies are moved back and forth to receive the pressure, and then to dump the tile onto a pallet.

For varying thicknesses or sizes of dies, provision is made to move the upper head up or down by means of screw and hand wheel. This adjustment can be made very quickly. The pressure exerted by the mechanism of this press is sufficient to make dry pres brick, hence for plastic clay ware it is ample at all times.

Its daily output depends largely upon the operator and the size of tiles made, but under average conditions it is possible to make 500 pieces, but more often the output will not exceed 300 pieces per day.

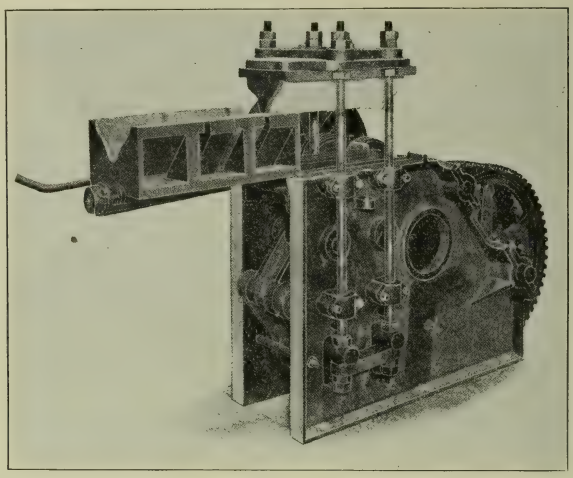

Fig. 72—The Grath Trimmings Press. (Illinois Supply & Construction Company.)

While this press has found quite a wide use among the roofing tile manufacturers, it has one feature that is not desirable. By reference to the cut it will be seen that the pressure is applied from below, raising the lower die up against the top die, which in turn remains stationary. This, however, should not be the case. The top die should be the one to move and the lower one remain stationary, for the following reasons: In the nature of the case, tile dies are heavy, and in addition to the dies, the weight of the track or dumping mechanism rests on the die platform, so that the man at the lever has a dead load, amounting at times to 200 pounds, to raise at the pressing of each tile. In part, this load is relieved by the side springs shown in the cut, but the tile manufacturer has so many dies to be used on a press of this kind that it is not usually possible to keep the springs properly adjusted to equalize the weight of each one.

The above objection to the press is possibly no more serious than having the sliding track moving up and down with each pressing. For various reasons it is desirable to have the track remain at one level, especially if the press is fed from both sides. Another objection to this press which will apply to all hand presses is that it requires two men to operate it properly, one at the die and the other on the lever. The same work can as well be done by one man if the press is fitted for power.

The Grath Trimmings Press.—Of the power presses for special work, this press has found a considerable use and well deserves its popularity. It is small and compact, requiring but very little floor space, and is easily operated by one man.

By referring to the illustration it will be seen that the press consists of two cast side frames, or housings, which practically enclose all of the working parts of the press. On the opposite side, back of the die in the cut, is the driving pulley. This is on a shaft, which in turn carries two pinion wheels, which drive the two large master gears shown at the back of the press. These carry a cam, which in turn operates a connecting rod that is attached at its outer end to the toggle joints shown below the die. When these toggles are pulled to a veritcal position they transmit pressure to the upper die by means of the four large rods working in guides at either side of the press. The lower die is arranged to slide in and out upon a rod to which it is hinged. It is a very easy matter to dump the largest dies by turning them over with the handle shown at the end of the die in the cut. For the proper adjustment of the upper die to suit the varying thicknesses, it is necessary to raise or lower the nuts on the four upright rods. If this feature were improved, the value of the press would be very much enhanced. In addition, the press should be built with a higher lift, it being now impossible to make ware of much depth. The weight is all below, and the lower die does not move up and down with the pressure, as in the Raymond press, both of which features are desirable.

American Trimmings Press.—It will be seen (Figure 73) that this press is built upon very different lines from those of the Grath press.

It consists of a main central frame, or housing, a part of which forms the journal bearings for the driving and crank shaft. Two upright guide rods carry the cross head to which the upper die is attached. It will be noticed that relieving springs are employed to allow a slight give to the cross head in case of excessive pressure.

The four connecting rods connect the crank pins, riveted into the crank gears at either side of the press. The crank gears are provided with counterweights to balance the upper cross head. The power is applied at the friction clutch pulley, which in turn drives a shaft carrying two pinions that engage the large crank gears. Suitable sliding track arrangements are made for the lower die. Considering this press as a whole, it should meet the demands of the roofing tile manufacturer and prove very satisfactory. Only one of these presses was found in use, but this design had not been on the market long at the time of taking the field notes for this report.

The Rogers Trimmings Press.—This press is built along quite different lines from those of the American or Grath. It is, in a general way, patterned after the Rogers pentagon press, in that the main housings and outbearings stand upon a heavy one-piece bed plate, thus making a much heavier, and at the same time a more rigid, press than those having outbearings resting on separate pillow blocks or foundations.

From the drawing on page 792 it can be seen that the press consists essentially of the solid bed plate, with the two outbearings on the right, while at the left are the two main housings. These are connected at the top by a heavy cast iron yoke.

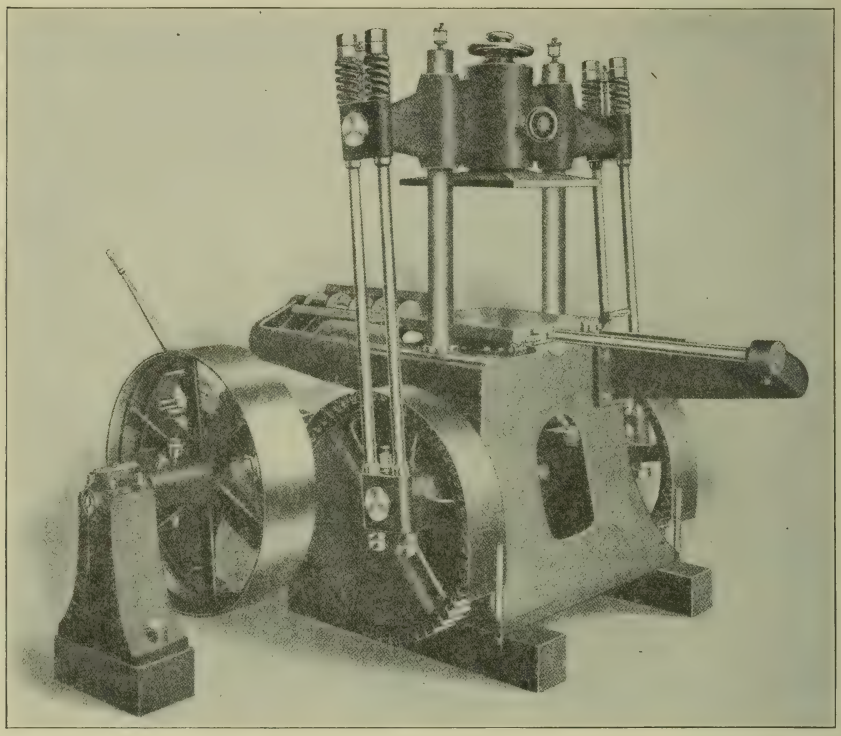

Fig. 73—Trimmings Press, made by the American Clay Machinery Company.

The driving mechanism of the press is of the double back-geared type. The main driving pulley is carried by the shaft resting in the bearings at the top of the outbearing blocks. This primary shaft, in addition, carries the pinion wheel at the extreme right, which meshes with the large gear wheel on the secondary shaft. The secondary shaft extends across the face of the main housings, being attached to the same by bearings. The power is delivered from the secondary shaft through the two small pinions to the large crank gear wheels, one on either side of the press and connected by a shaft. From the crank wheels the power is delivered to the main cross-head by heavy rods, two at either side of the press.

The cross-head is made very large and heavy, and travels or reciprocates in guides formed by the side housings. Attached to the cross-head is a large face plate, to which the dies can be bolted. A convenient arrangement is provided to raise and lower this plate so that it can be adjusted to suit different dies and to regulate the thickness of the ware.

The main table upon which the lower die is carried rests on a heavy casting or bed plate which extends from housing to housing. The die table is conveniently arranged to move out from under the press to facilitate the filling and dumping. The press is built so that either a single or a double dumping table can be used.

Experience in the past has been that it is more satisfactory to operate any trimmings press from one side only. The better practice where greater output is desired is to use two presses.

The Rogers press has found a wider use than any of the other trimmings presses described in this report. It has, however, been on the market longer than most of the others, but in turn it has a number of excellent features. It is self-contained, double back-geared, the main housings are heavy and large, thus forming exceptionally good bearing surfaces for the guides. The adjustments of the upper die can be quickly made, and furthermore the lift of the upper die is ample to care for ware of high projections.

Mueller Hand Press.—This press is quite small and is arranged for hand driving. It is operated by taking a previously prepared blank of clay and placing the same on the lower die, which is between the hand crank and the large gear wheel. The upper die is then pulled down into position. The roller pins at each end of the die engage with the cam or eccentric wheels attached to the main gear wheel shaft. The crank, which is back-geared against the main gear wheel, is then turned until the cams have made one complete revolution. The roller pins of the upper die thus being released, the die is raised. A pallet is now placed over the tile resting in the lower die. This die is so hinged that it can easily be turned over, thus emptying the freshly made tile onto the pallet. The die is then turned back into its proper position ready for a second tile.

There is little that can be said in favor of this press, although by arranging to drive it by power so that its speed would be increased it is quite possible that it could be used on special or complicated tiles and trimmings. As it stands though, it is quite foreign to the American way of doing work. While a number of these presses have been placed in drain tile and brick plants for the manufacture of a few roofing tiles, none of them have found their way into any of the true roofing tile plants.

Laeis Trimmings Press.—It will be observed that this press is different from the American presses. Its essential parts are as follows: The driving pulley at the right is carried on a shaft supported by an outbearing and a boxing attached to the main housing or frame of the press. This primary shaft is back geared against the large gear wheel shown on the upper right hand side of the press. The shaft to which the large gear is attached extends through to the other side of the press, carrying at the center an eccentric hub which

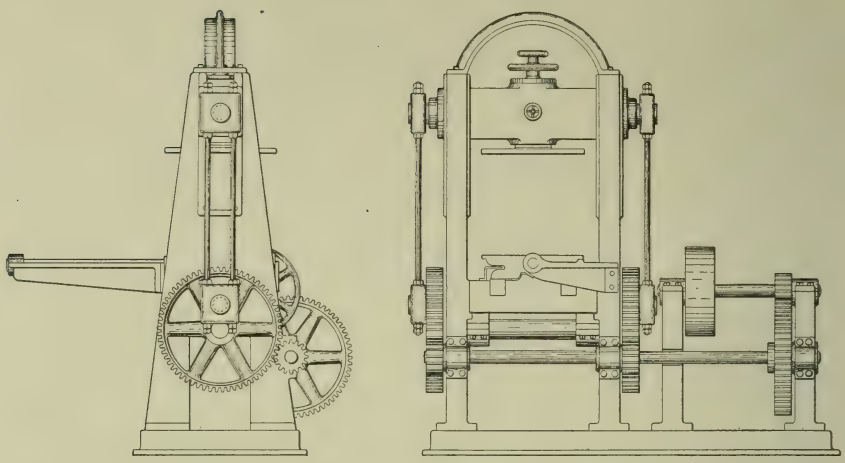

Fig. 74—The Rogers Trimmings Press.

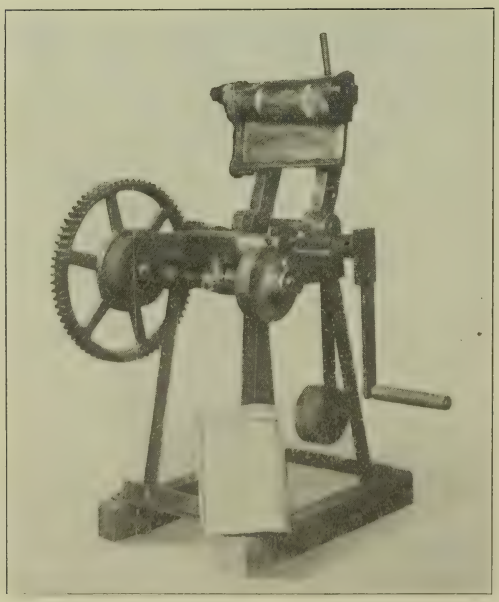

Fig. 75—The Mueller Hand Press.

works against a roller attached to the cross head or plunger. Thus as the eccentric hub on the shaft revolves, the plunger is alternately raised and lowered carrying the upper die with it. The lower die which rests on the bed plate is provided with a sliding track to enable the operator to change and empty it easily. Probably the strongest feature about this press is the placing of the greater part of the gearing above the dies, thus keeping them free from the scrap clay.

Jaeger Trimmings Press.—This press is of the same type as the imported German trimmings press used at the Chicago Heights plant of the Ludowici-Celadon Company.

From figure 77, page 795, it can be seen that the press is built low, heavy and self-contained. The power is transmitted from the driving pulley to the plunger through a long lever or walking beam. While the latter is continuously in motion, the pressure only takes place when the small lever above the upper die is pushed into position by the operator. After each stroke, however, the lever is automatically disengaged as a safety precaution.

It will be observed that this press is so constructed that the dies operate at right angles to the body of the press, and furthermore, the dies are accessible at any point on the sliding track. This feature is of value in case the piece of ware should fail to fill out perfectly and it is necessary to add more clay and press a second time. In the ordinary press the lower die will have to be pulled out from under the plunger in order to add the extra clay.

In this case as in the press shown in figure seventy-six, the gearing is removed as far as possible from a point where it would be in danger of becoming fouled with the scrap clay.

The Klay Trimmings Press.—By reference to the cut (Figure 78) it will be seen that this press is entirely different from any others thus far described.

It consists of four upright frame posts, connected at the top by a heavy casting, which carries the upper die and the mechanism for adjusting the position of the same to suit dies of various sizes. The lower die rests upon a movable table, or plunger, working between guides. Just below and connected to the table, are the toggle joints which transmit the pressure to the die.

The toggles are operated by a long connecting rod which is operated by the cam gears shown on the left of the cut. These cam gears and all the balance of the driving mechanism are attached to an extension of the main frame work.

While the press is undoubtedly very powerful, it has some bad features. Among them are, first, the lower die is moved instead of the upper; secondly, the press is very bunglesome, requiring an undue amount of floor space to accommodate the driving mechanism. More space is taken up by this part alone than is used by the press proper.

One press of this make was found in use during the season of 1908.

Tile Trimmer.—Mention was made of a trimmer in connection with the descripion of the Klay roofing tile press, used to make the sides or edges of the tile smooth and perfect without subsequent work.

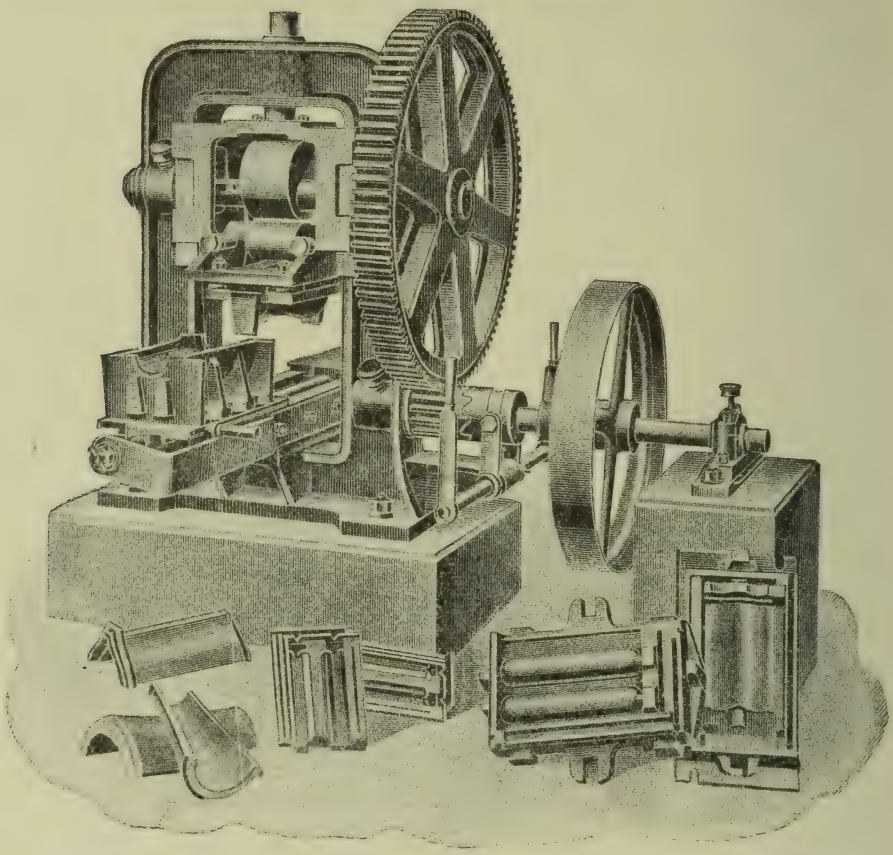

Fig. 76—The Laeis Trimmings Press, made by E. Laeis & Company, Trier, Germany.

With the ordinary dies used on tile presses, it is customary to have the edges of the upper and lower dies meet at a point about midway in the thickness of the tile; that is, the tile is half in the upper, and half in the lower die. It is impossible to keep dies in such perfect condition that they will shut absolutely tight along their sides for any length of time. The issue of the clay soon wears the sharp edges away. Thus, after a tile has been pressed in such a die, it will be found upon being removed to have a ragged seam or "feather edge" on the line where the two dies divided. This feather edge of clay must be trimmed off, and as a rule two boys or men are required at each press to do this work. With plaster dies, the trouble is much worse than with metal dies. To do away with the expense of "skinning" the tiles, as it is called, large

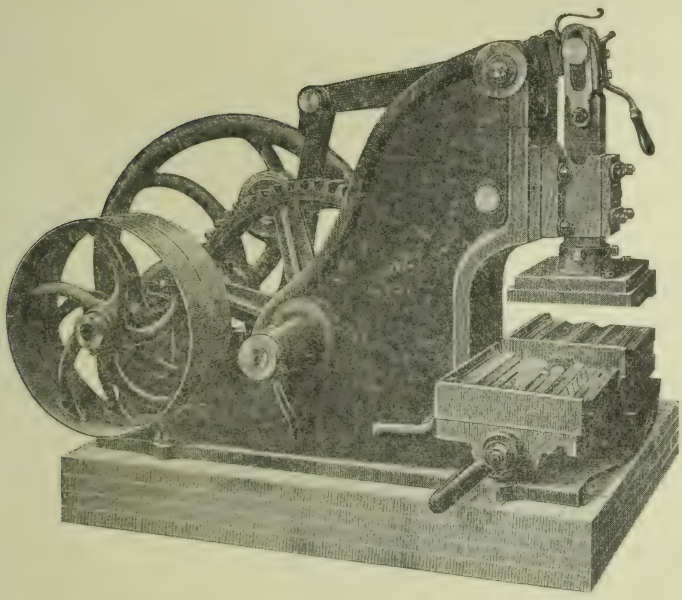

Fig. 77—The Jaeger Trimmings Press.

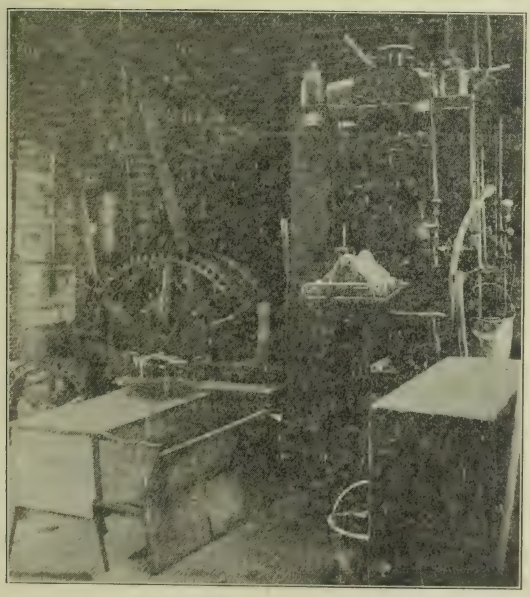

Fig. 78—The Klay Trimmings Press. (National Works, Lima, O.)

sums of money have been expended to perfect a trimmer that would do the work automatically on the press. The great trouble has been to prevent the clay from squeezing out between the trimmer and die; in this case the feather edge is only changed in position. A trimmer, to do good work, has to be made to fit the die snugly, and if so, at times it will bind, failing to pass over or release from the die, and it or the press is then broken.

So far the only successful trimmers that have been made to work are those used on metal dies.

The trimmer giving the best satisfaction was in use at the plant of the United States Roofing Tile Company, at Parkersburg, W. Va., and was devised and worked out by them. In outline the trimmer is about as shown in the following drawing:

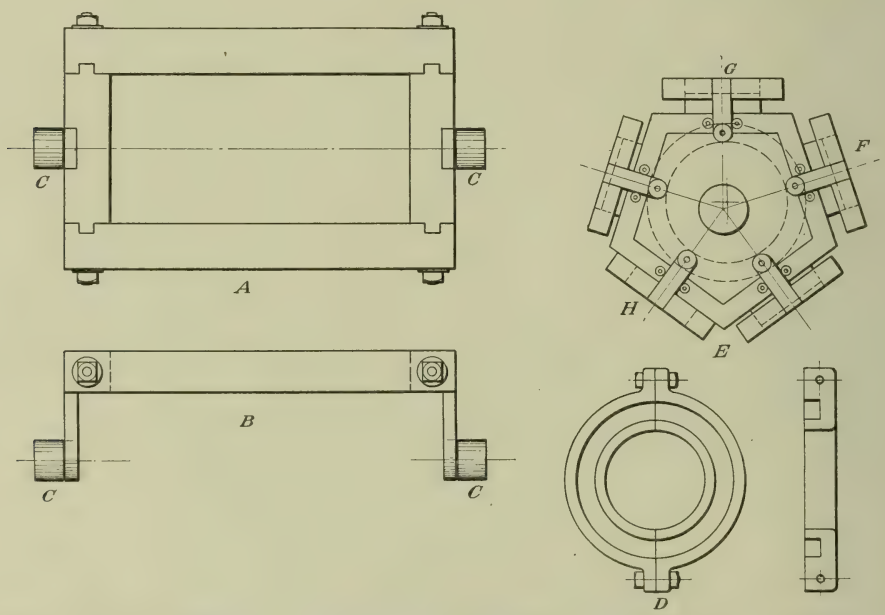

Fig. 79—Tile Trimmer, in Use at the United States Roofing Tile Company.

The trimmer consists of two parts, the frames A and the track D. A represents a top view of the trimmer. It is nothing more than a steel frame made to encase the die. At the two ends of the frame are shown rollers, C. The side view B of the frame shows the position of the rollers in reference to the frame; they are attached by lugs projecting downward.

D represents the track, in which the rollers of the frame work. At E is shown an end view of the press pentagon with the five dies and trimmers attached. The track as indicated by the dotted line is placed out of center with the pentagon, being highest at the upper and feeding

side of the press. The track of course is attached to the side frames of the press, and does not move.

The operation of the trimmer is as follows: The blank of clay used to make the tile is fed into the die at F. The trimmer at this point is nearly at its full height. The pentagon revolves to G, and the trimmer is at its highest point. The top die comes down, entering the trimmer-frame by a very tight fit and the pressure is made. The top die then lifts and the pentagon turns. When the die has reached H, it will be seen that the trimmer is drawn back to the full depth of the die, thus releasing the tile which is caught on the pallet. The fact that the trimmer has held the edges of the clay in while under pressure, and while moving downward it has smoothed the sides, makes it possible to produce tiles that do not need trimming.

Much could be done along this line that would be of great benefit to the industry.

PATENTS ON ROOFING TILE MACHINERY.

The records of the Patent Office show that great quantities of machines have been devised and patented. Few have become of more than temporary importance. For the convenience of others who are looking up this subject, the following list has been prepared, of the patents taken out on roofing tile machines.

Date of Issue.	Name of Inventor.	Serial Number.	Remarks.
June 12 1855	G. Graessle ..... Address not given.	13,059	Dies attached to endless chains, and made to pass between rollers for the necessary pressure.
Dec. 29 1868	P. A. Brown..... Indianapolis, Ind.	85,362	Die boxes or frames in which the tiles are formed. Pressure applied by levers.
April 13 1869	Charles Messenger .... Cleveland, Ohio.	88,795	Design of a pentagon press to be operated by hand; pressure being delivered through levers. Probably the first design of a pentagon press in the United States.
Aug. 2 1870	John B. Hughes..... Terre Haute, Ind.	106,062	A table and frame in combination with die boxes upon which tin and muslin were used to prevent the clay from sticking. Pressure applied by levers.
Aug. 23 1870	Joseph Christen ..... New Orleans, La.	106,550	Design for a pentagon press; a better design than that of No. 88,795.
Jan. 10 1871	John Koehler ..... Warren, Ohio.	110,859	A roller having the die or one face of the tile impression attached. The other half of die with its clay charge was pushed under the roller, thus receiving the imprint. A very poor machine for the work.
June 27 1871	John B. Hughes..... Terre Haute, Ind.	116,447	Similar to No. 110,859, though more practical.
Aug. 27 1872	Calvin J. Merril ..... Upper Alton, Ill.	130,856	Dies for diamond tiles attached to segments of rollers, which in turn are revolved through a short arc bringing the dies together.
Sept. 9 1873	Calvin J. Merril..... Upper Alton, Ill.	142,576	Dies attached to large rollers or wheels which press the dies together as they revolve.
Mar. 13 1877	Jacob Greenawalt ..... Pittsburgh, Pa.	188,291	Design of a press having a three-sided die holder instead of the usual pentagon. Tiles to be delivered onto a belt beneath the press. Design is of doubtful value.

Date of Issue.	Name of Inventor.	Serial Number.	Remarks.
Dec. 4 1877	Horace B. Camp ..... Cuyahoga Falls, O.	197,718	Design of a press having a horizontal revolving table to carry the dies under a plunger for the pressure. For some classes of roofing tile work this press would be of value.
Dec. 23 1884	Carl Schlickeysen ..... Berlin, Germany.	309,568	An after cutter and former for auger-made interlocking tiles.
April 5 1892	John E. Donaldson ... Montezuma, Ind.	472,189	Design for a metal tile die.
Dec. 13 1892	George H. Babcock.... Plainfield, N. J.	488,049	Design of a press upon which the dies are brought together as a pair of jaws. This press was for several years in use at Alfred, N.Y.
Mar. 14 1893	Wilhelm Ludowici..... Jockgrim, Germany.	493,366	Design for a pentagon press. The pressure is applied by power through eccentric-shafts. This design shows the spider and trip wheel for dumping the dies.
Jan. 23 1894	Joseph Rapp ..... New Philadelphia, O.	513,140	Design of a machine or cutter for cutting auger-made Spanish tiles.
April 14 1896	Karl Thomann..... Halle, Germany.	558,326	A hand press better adapted to cement tiles than those of clay.
Dec. 22 1896	Gustav Krebs..... Halle-on-the-Salle. Abraham Weil, Steinheim, Germany.	573,604	A complicated hand press; would be better for cement than clay.
June 15 1897	Franz Kunzemann .... Eilenburg, Germany.	584,374	Design of a pressing table for molding tiles in dies by hand in connection with tamping and scraping arms. Would probably be of more service for cement than clay tiles.
Jan. 18 1898	Abraham Weil ..... Steinheim, Germany.	597,447	Hand press for forming tiles, very complicated.
July 26 1898	John C. Merrill..... Alfred, N. Y.	607,870	A press having a horizontal die table which carries the dies under the plunger. Was originally designed for the manufacture of dry pressed tiles.

Date of Issue.	Name of Inventor.	Serial Number.	Remarks.
Dec. 6 1898	A. B. Klay, G. Jennings and F. Ewing..... West Cairo, Ohio.	615,560	Toggle joint press, for description, see Fig. No.71, page 786
Mar. 7 1899	Carl H. D. Wicke ..... Lehe, Germany.	620,817	Hand press for forming cement tiles.
April 10 1900	Abraham Weil ..... Steinheim, Germany.	647,431	A drop or hand tamping press for cement tiles.
Oct. 2 1900	Richard Lesch ..... Bruno Polte ..... Konstadt, Germany.	658,791	A machine consisting of a roller die under which pass the opposite dies moved by endless chains.
Mar. 12 1901	Wilhelm Ludowici..... Jockgrim, Germany.	669,535	Improvement on trip and escapement wheel of pentagon presses.
Nov. 26 1901	Abraham B. Klay .... Ottawa, Ohio.	687,688	Toggle joint press illustrated and described in Fig. No. 71. An improvement over patent No. 615,560.
Aug. 12 1902	Xavier P. Gilardoni ... Choisy-Le-Roi, France	706,926	Design of a pentagon press for making hollow interlocking tiles.
Mar. 22 1904	Louis Strenli..... Zurich, Germany.	755,253	Design of a revolving horizontal table press for cement tiles.
May 31 1904	John W. Campbell .... Colorado Springs, Col.	761,201	A screw press and die for making cement tiles.
Nov. 7 1905	William P. Meeker ..... Newark, N. J.	803,700	Mold or casing for making tiles by hand.
Nov. 14 1905	Henry Meyer ..... Warren, Ohio.	804,753	Dies or forms for making cement tiles.
Nov. 21 1905	Alfred Gaspary ..... Markranstadt near Leipsic, Germany.	804,944	Outfit for making cement tiles.
Nov. 13 1906	Alfred Gaspary ..... Markranstadt near Leipsic, Germany.	835,858	An improvement on patent 804,944.
July 30 1907	Samuel A. Jones ..... Deshler. Ohio.	.....	Hand press with die forms for making cement tiles.
Oct. 13 1908	William Pugh..... Streator, Ill.	900,778	A die frame or box over which a roller is passed to press the material, cement or clay, into the proper form.

NOTES ON THE MANUFACTURING OPERATION.

The foregoing descriptions have set forth more or less superficially the types of machinery used in the preparing of blanks for roofing tiles and for actually making the tiles and finishing them. In applying the machinery to the different shapes of tiles, a great variety of practice was found, of which it is the intent to give a resume.

The Forming of Shingle Tiles.—The use of shingle tiles has made its greatest development in Germany, and naturally its greatest development in its method of manufacture has there occurred.

As shown in Chapter II, there are many forms of shingle tiles. The plainest and simplest are merely the flat slabs of burnt clay, usually three-eighths of an inch or one-half inch in thickness, by five or six inches in width, and twelve to fifteen inches in length. They may be made with ribs, lugs, interlocking features, ornamented and grooved surfaces, etc. The more complicated they are made, the less distinction remains between them and the regular interlocking tiles.

Plain Tiles vs. Lugged Tiles.—Plain shingle tiles may be fastened to the roof by two nails, driven through perforations made when the tiles are soft, or by hanging the tiles by lugs on their under surface, which hook over the edges of the roof purlins. The former method is in use almost exclusively in America, while the lugs are the usual method in European countries.

There are several points in favor of each method. Taking up the lug method first, the following points may be made:

First. Nails are dispensed with. It is claimed that nails will in the course of a few years rust off, allowing the tiles to slide down off the roof.

Second. It is difficult to insert new tiles on roofs that are nailed on. It is impossible to raise the tiles that are in place sufficiently to allow putting in new ones. With lugged tiles, it is only necessary to push the new tiles up under the old ones, until the lug catches over the purlin.

Third. Tiles with lugs are less apt to break when on the roof than nailed ones. In nailing tiles it frequently happens that the roofer drives the nails down too tight on the tiles. This lifts the outer ends, and puts the tiles under a strain, so that it takes only a slight jar or a load applied to the outer end of the tiles to break them. In the case of the lug tiles, each one hangs loose and free, thereby allowing for expansion and contraction and for irregular loading, as in walking on the roof while under erection or in the process of cleaning, removing snow, etc.

In favor of nailing shingle tiles in place the following reasons may be brought out:

First. For siding purposes the nailed tiles have the advantage; in fact, lugged tiles cannot be used for this purpose unless other provision than the lug is made to hold them in place.

Second. In manufacture the lugged tiles are somewhat more complicated than the nailed tile. In the lugged tiles it is necessary to provide special cutters to remove that part of the rib of clay along the back of the tiles that is not needed for the lug. The Germans, in particular, have in use many excellent cutters for this class of work.

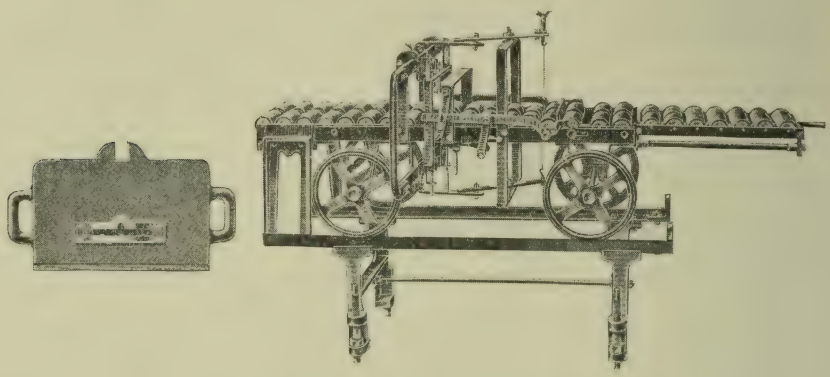

Fig. 80—Single Stream "Beaver Tail" Shingle Tile Die and Cutter, made by Th. Groke, Merseburg, Germany.

They not only have cutters that will take care of a single bar of clay, but cutters that will handle two bars of clay with two tiles to each bar.

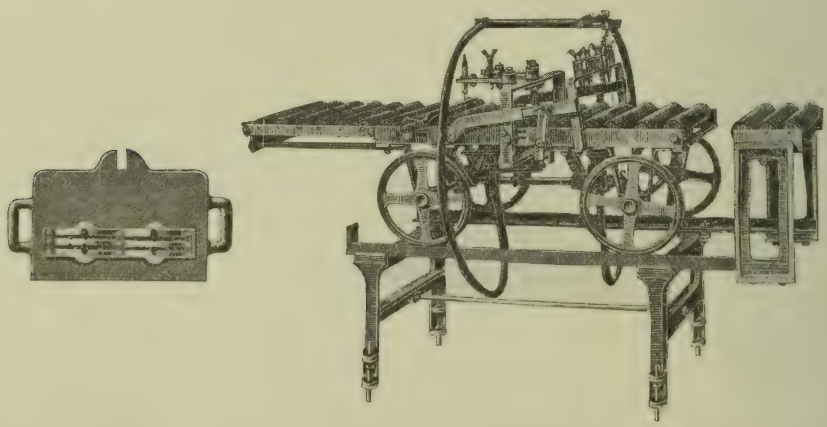

Fig. 81—Quadruple Stream "Beaver Tail" Shingle Tile Die and Cutter, made by Th. Groke, Merseburg, Germany.

Third. Tiles with lugs require more clay than nailed tiles. In a plant producing twelve thousand shingle tiles per day, from five hundred to eight hundred pounds more clay will be used making tiles with lugs than would be required in making the straight bar. This extra material takes up a proportionately increased amount of heat in drying

and burning. This item is not of serious weight, but its effect is adverse to the lugged tile.

Fourth. Tiles with lugs are more troublesome to handle in the setting of the kiln and at other points, on account of the fact that every other tile must be reversed in order to allow them to nest tightly.

It can be seen from the above that each shape has its shortcomings. The American tile manufacturer seems to be very much in favor of the plain shingle tiles with nail holes. Not a single instance of the manufacture of shingle tiles with lugs was to be found in this country in 1908. It would seem, though, that the manufacture of lugged shingle tiles, could be profitably taken up by our factories. This style of tiles would unquestionably meet the approval of the architects, and at the same time would be gladly accepted by the roofers as soon as they found that a roof could be covered in much less time. Of course the roof would have to be stripped with purlins, but these would not require one-tenth of the amount of nailing that a complete covering of tiles would require.

As to the cost of manufacture, it is believed that lugged tiles can be made as cheaply as the ordinary hand-punched kind if cutters of proper design are employed.

Popularity in United States—In the United States, the manufacture of shingle tiles is not very extensive. There were only two plants working exclusively on this style of tiles in 1908. Nearly all of the other roofing tiles plants also make shingle tiles, but they are only an unimportant side line in most of them. Hence at the above two plants, where the entire output is of shingle tiles, it is natural to expect to find their manufacture developed to a much better degree than in those plants where only a few are made.

The manufacture of shingle tiles has given more trouble to the roofing tile manufacturers than all other styles combined. At first thought it would seem that the simplicity of shape and the small size of the tiles would decrease the difficulties of manufacture, but the reverse has proved true. It is doubtful whether there is in the entire clay industry any ware more difficult to produce with good degree of mechanical perfection at the proper degree of vitrification than a plain, simple shingle tile. The fact that it is plain is what makes it a hard problem. To keep it perfectly straight and true during the drying and burning is the trouble. It will be found that tiles with reversed curves, like the Spanish or interlocking forms, are much easier to hold straight, owing to the curves acting as braces on the ribs to prevent warping. In the plain shingle tiles there is nothing to prevent their warping like a green board exposed to the sun.

Then, too, the shingle tiles are very prone to a trouble known as "side checking." These are cracks proceeding in from the edges of the tile

about one or two inches. Also, the shingle tiles are the most apt of all kinds to "centermark" during the burning.

The side checks are due very largely to faulty die construction; that is, the clay along the sides of the tile does not receive the same pressure, while passing through the die, that the central portion of the tile does; hence the two portions are of different density, and will shrink at a different rate, producing cracks. Even if no difference in density can be found, the difference in pressure results in a difference in speed of flow. The bar of clay is like a stream whose current is swiftest in the center and slower along the banks, where it is retarded by friction. If the center of the clay bar flows even one-eighth of an inch faster in twelve inches than the sides, this difference is likely to result in cracks aggregating one-eighth of an inch in width. But the crack also leads to the bar tearing and ruffling up so that no smoothing down by hand or otherwise will eradicate the defects thus initiated.

Methods of setting and burning also play a large part in side-checking shingle tiles. As a rule, in the endeavor to set them so they cannot warp or twist they are set too tight for the heat to penetrate them rapidly, and are then burned altogether too fast. This means that a compact mass of tiles will act about as a solid block of clay would do. The exterior of the pile, receiving the heat first and longest, will shrink and vitrify more than the central parts, resulting in side checks. This point, however, will be treated more fully under the heading of methods of setting tiles.

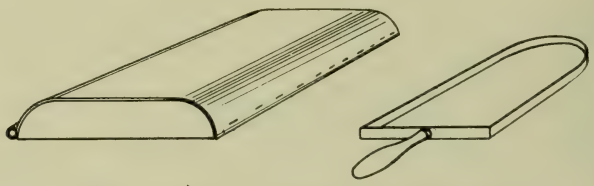

Fig. 82—Hand Mold for Shingle Tiles.

Early Modes of Manufacture.—In the beginning, shingle tiles were no doubt roughly formed by the hands upon a flat area of bare ground, or upon flat stones. Following this, it would only be natural for man to carve out of wood molds or possibly molds of burnt clay, into which he could press the soft clay, and at this state of development, the industry must have stood for many centuries. With the discovery and use of cast iron, the use of this metal for dies naturally entered the field, and still remains an important, but not exclusive, material.

Hand Pressing in Marginal Ring.—In figure 82 will be seen an outfit still in use in many of the smaller plants in Europe. It consists of two parts, first, a piece of plank, over which is spread a piece of canvas or other cloth. This cloth as shown, is tacked along one edge of the block, and is spread upon the surface, covering it completely. It is

is held smooth and taut by an iron rod B, which is sewed into the margin of the cloth, like a curtain pole. The second part of the outfit is the iron frame C. This frame is made with the inside shape and dimensions of the desired tile in the green condition. This frame is placed on the canvas surface of the block, and the previously prepared clay is batted into the iron frame by the hand or by a wooden paddle or "batter," until all parts of the frame are filled. A straight edge or stick or metal scraper is then drawn over the top surface of the clay, cutting it down to the level of the sides of the frame, which thus controls the thickness of the tile produced. A board or pallet of about the same outline as the tile, is now held upon the surface of the clay, which is usually well smeared with a fine red-burning sand. The iron marginal frame is now raised until free from the tile and the tile is "delivered" on the pallet by placing the right hand on the pallet and raising the free edge of the canvas and thus upsetting the slab of clay. The bottom side is then sanded and the pallet carried out to the yard to dry in the sun and wind.

Hand Pressing in Plaster Dies.—Another method for making shingle tiles by hand employs moulds made of plaster of Paris.

These moulds are made in one piece, so that after pressing and pounding or "batting" the clay into the mould, and scraping off the excess, much as in the case of the preceding method, the clay must remain in the mould for possibly an hour to allow the moisture to be absorbed by the plaster mould and the clay to shrink loose from it. Each workman must, therefore, be provided with enough moulds to keep him busy for an hour or more, i. e., enough to enable him to work continuously.

The above methods are of course very crude, and would prove impracticable in this country with our expensive labor, unless it might be on some special order, where genuine hand-made tiles are desired and the price paid is sufficient to warrant making them after this old-fashioned manner. Such cases do arise, and with increasing frequency, as architects give more attention to the reproduction of old types of buildings.

Shingle Tiles by Hand Power Presses.—While it is possible to make shingle tiles on hand presses as perfectly as on any other, very few if any are made in that manner in this country. In foreign countries, where labor is cheaper, some forms of shingle tiles are still made on the hand-power press, but in the nature of the case, since the shingle tile is the easiest form to make by expression through flow dies, very little work is now done by hand-power presses except for odd pieces, such as miter tiles, valley tiles, gable, and sometimes tower tiles.

Shingle Tiles Manufactured by Flow Dies.—It can safely be said, that at least ninety per cent. of all shingle tiles are now made by this

method. The general simplicity of outline of this variety of tiles would indicate its adaption to this method of manufacture. Shingle tiles, as made in this country, are cut from a ribbon or thin flat bar of clay, usually three-eighths to one-half inch thick by five to six inches wide, in lengths of twelve to fifteen inches. The types of machinery used have been discussed earlier in this chapter.

Shingle Tiles by Plunger Machines.—The sole plant using this method of manufacture in 1908, the Cincinnati Roofing Tile and Terra Cotta Company, of Winton Place, Cincinnati, Ohio, has been described with care in connection with the plunger machine and will not receive further consideration here.

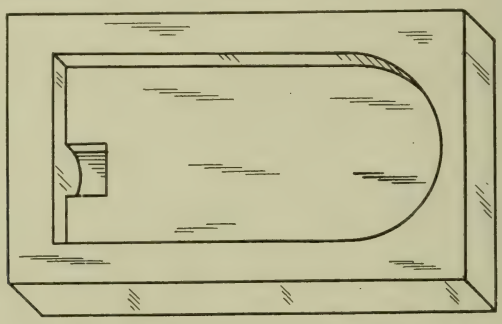

Fig. 83—Plaster Mold for Shingle Tile.

Shingle Tiles by Auger Machines.—As the only two plants occupied solely in shingle tile manufacture are both using the auger machine, it follows that the larger part of the shingles in this country are produced by this method. These plants are the Huntington (W. Va.) Roofing Tile Company, the oldest, and the Murray Roofing Tile Company, of Cloverport, Ky.

The dies through which the tile bar is extruded, constitute really the only critical or characteristic feature of an auger machine for roofing tile purposes:

Shingle Tile Dies.—Much attention has been given to the matter of shingle tile dies by the various roofing tile manufacturers, each in turn having devised a die that in their estimation is the acme of success. They usually guard the details of their die with much secrecy. It is questionable, however, whether this policy is a profitable one.

Without doubt, each die in successful operation has its points of excellence, and represents an asset to the company using it, but to any other concern, with clay of different physical properties, it is quite unlikely that it would prove satisfactory. Hence, by an open discussion and comparison of notes on this point, much valuable information could be given and received, and each concern would be established more safely with a knowledge of the principles rather than of unassorted facts.

The Cincinnati Shingle Tile Die.—The shingle tile die in use by the Cincinnati Roofing Tile and Terra Cotta Company is a duplicate of their Spanish tile die (see Figure No. 98) with the exception of the form of the tile. Hence a description is unnecessary at this point.

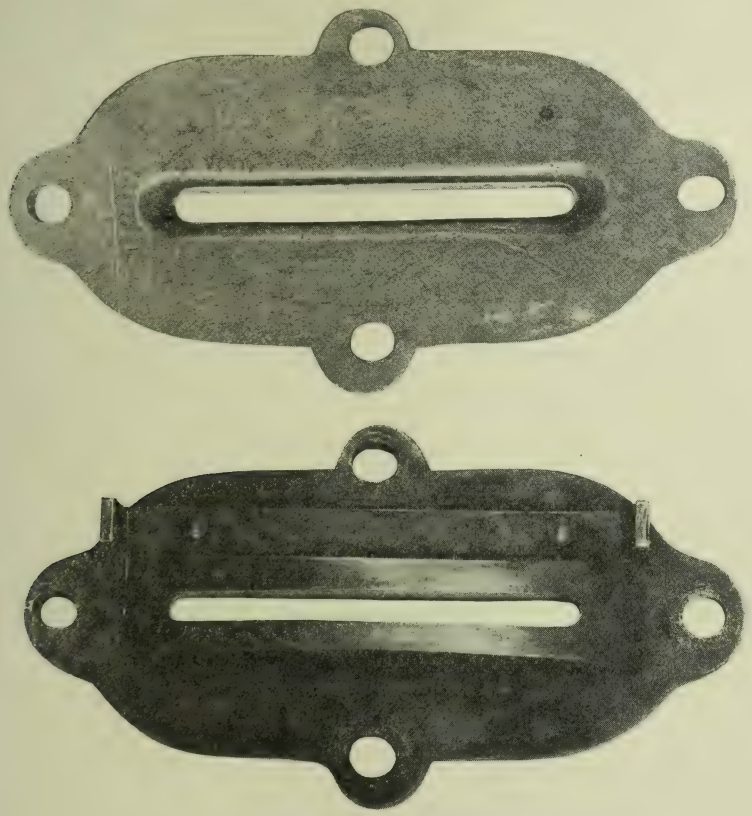

Fig. 84—Mueller Shingle Tile Die.

The Mueller Shingle Die.—From the illustration it can be seen that the die is a very simple one, nothing more than a plain casting with the necessary opening for the clay. The corners are belled or coned out as shown, to increase the flow of clay at those points. There is a serious objection to this style of die, that is, the die cannot be closed in as it wears away. Thus in a short time the entire die must be discarded, while if made in halves, it could be closed in and made to do service much longer.

The Parkersburg Die.—The die in use by the United States Roofing Tile Company at Parkersburg, W. Va., is one devised by themselves.

By reference to Figure No. 86 it will be seen that it consists of two parts, a head plate for the auger machine, and the die proper. The head plate is made with friction bosses to hold back the flow of the clay

at the center of the tile, while the corners or edges of the die in the head are rounded out to allow a greater flow of clay to enter these parts. The real opening through the head plate is somewhat larger than the mouth

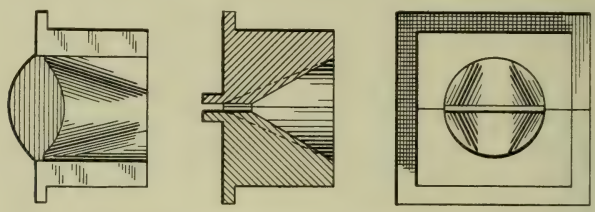

Fig. 85—The Murray Shingle Tile Die.

piece that is attached by bolts to its face. The mouth piece is made in two parts, to permit closing in as the die wears away.

It will be found in the constructing of a die for running tiles, that provision must be made to restrict the flow of clay at the center of the

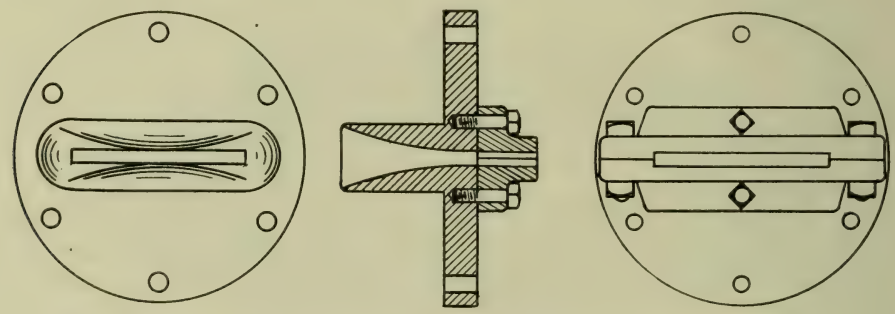

Fig. 86—Shingle Tile Die used by United States Roofing Tile Company.

tiles, and to facilitate it at the sides. The extent to which this will be necessary will vary with different clays.

Another style of die that was for a long time used at the plant of the Chicago Roofing and Siding Tile Company, at Ottawa, Ill., and made by H. Brewer & Co., of Tecumseh, Mich., was similar to Figure No. 87. The only essential difference between this die and the one before mentioned is that the former is known as a dry die; that is, no heat or lubricant is applied to facilitate the flow of clay, while in the latter, the use of oil is provided for, making what is known as a wet or lubricating die. By referring to the cut it will be seen that the feed of oil takes place at the edges of the stream of clay and at an opening between the head plate and the mouth piece. This die gave satisfactory results.

It is believed that our manufacturers should make more use of steam heated and lubricated dies than they do, and that less trouble would be encountered from side-checked tiles than now exists.

Shingle Tile Cutters.—The problem of cutting the shingle tile bar as made by the American manufacturer, is much more simple than that of the foreign countries, especially Germany, where it is not only

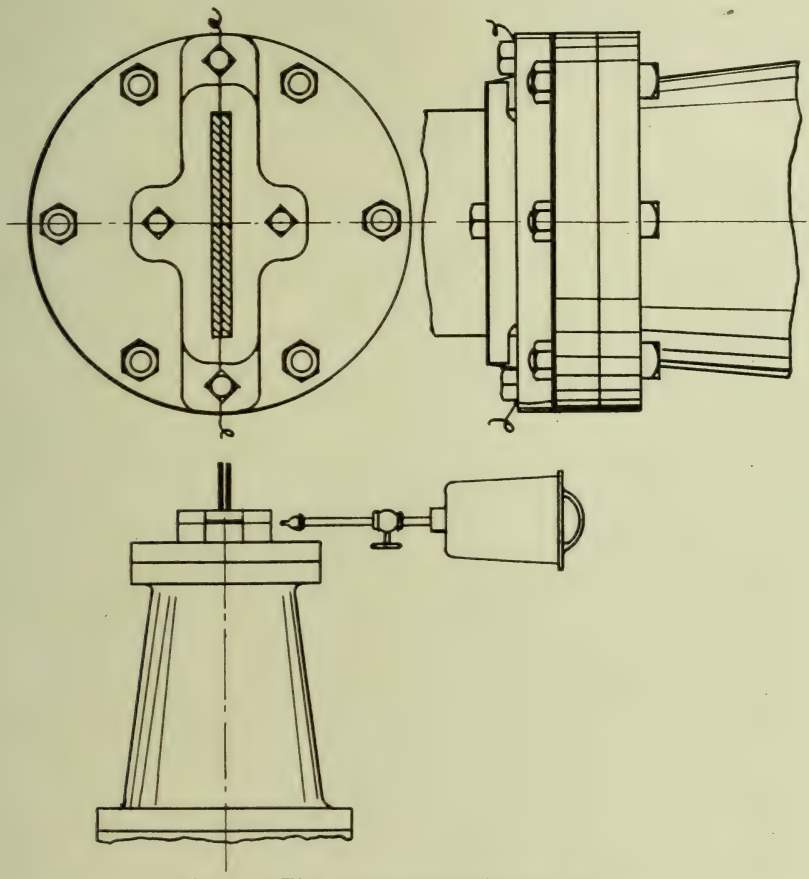

Fig. 87—The Brewer Shingle Tile Die.

necessary to cut off and remove the lug strips from the bar but also to cut the tiles with a rounded end, and as mentioned before, often double or quadruple streams are to be cut by one movement of the cutter. This feature has been shown in Figure No. 81.

The American auger-machine shingle tiles are run out from the die in single streams only, and are cut with a square or straight end. This simplifies matters very much; all that is necessary to do this is a form of reel cutter. The one most in use is shown in Figure No. 88. It is made by Mueller Bros. of St. Louis, Mo., but is also sold by the Illinois Construction & Supply Co., of St. Louis.

The clay passing over the roller A, causes the reel to revolve. At the ends of the reel arms are stretched the wires, which come in contact

with and sever the tile at B. A pallet is inserted on the endless belt at C. As the tile moves forward on the rollers the front end is caught by the up-coming pallet and as they both move forward the tile is transposed to the pallet. The attention of one person is required to feed in pallets and help to press the tile onto them. The pallet and tile move along on the belt to the off bearer, who places them on a near-by rack car.

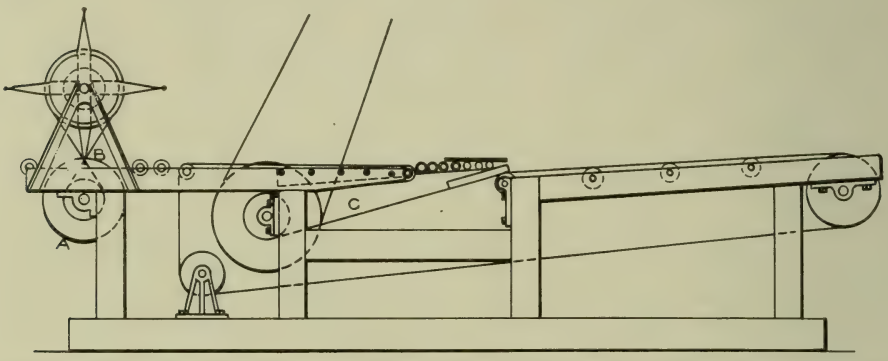

Fig. 88—Mueller's Reel Shingle Tile Cutter, sold by the Illinois Construction & Supply Company, St. Louis, Mo.

This style of cutter is very satisfactory and economical to operate, it being possible to cut and place on pallets with the labor of one man, the entire output of an auger machine, or in the neighborhood of twelve thousand tiles per day.

At the plant of the Ludowici-Celadon Company, New Lexington, Ohio, where a Bonnot auger machine was being used to make shingle tiles, it was noticed that a reel cutter was being used to cut the shingle tiles, but instead of using the system just described to get the tiles onto the pallets, two men were employed with special trowels to take up the tiles from the endless belt, and place them on the pallets.

This method cannot be recommended for several reasons, one being that it requires the labor of two men in the place of one, and secondly, in order to get the trowel under the tiles on the belt, the operator is very apt to mar the ends of the tiles, or possibly start cracks by twisting them or allowing them to bend.

Again, in removing the tiles from the trowel and onto the pallet, he is apt again to bend the tiles or possibly not place them straight on the pallet. In the latter method, however, it is possible to place two or more tiles on the same pallet, while in the case of the self placing system, only one tile can be put on a pallet.

While some of the reel cutters in use were home-made, such firms as the J. D. Fate & Co., Plymouth, Ohio; Mueller Bros., St. Louis, Mo.; and the Illinois Supply & Construction Co., of St. Louis, Mo., have furnished cutters of the type most in use.

Other Methods of Making Shingle Tiles by Flow Dies.—There are a few other methods of manufacturing shingle tiles that have been used with more or less success from time to time in this country, but more frequently in the old world. All of these methods involve running out a bar of some other cross-section than that of a shingle roofing tile slab, and then cutting this bar up lengthwise, as well as crosswise to increase the yield of tiles and decrease the power consumed in expressing a bar of such small cross-section. There are four such processes worth mention.

Splitting a Simple Rectangular Bar.—Only in one instance is this method known to have been successfully carried on in this country. During 1899, the Celadon Terra Cotta Company, of Ottawa, Ill., was producing tiles by running a stream of clay by auger machine through a Brewer die of approximately one inch by six inches cross-section. A fine piano wire was attached to the mouth piece of the die, in such a manner that the clay column was split horizontally into two streams, each being one-half inch thick (see Figure No. 87.) This split stream was then cut into lengths by a home made cutter which worked from side to side of the stream, punching and counter sinking the nail holes in both the upper and lower tiles, as it did so. The two companion tiles were placed on the same pallet and dried together, but just before going to the kiln, they were separated by inserting the blade of a case knife between them.

While this method of producing shingle tiles was cheaper, it was found the tiles did not sell as well as the single stream tiles, owing to their under surface being rough from the wire cut. The tiles were also seemingly somewhat weaker than the regular single stream tiles.

The principle of forming two tiles at once was good. It would seem that its use could well be extended, but it would be better to have the tiles issue from the machine separately, one above the other, thus giving two perfect tile bars, from which tiles with both surfaces finished could be cut. The streams would come together before reaching the cutter, and from there on could be handled as a single tile, thereby saving pallets, dryer and kiln space and labor.

Cutting a Solid Bar Into Several Tiles.—It is not known that this system has been used at all in this country, but in the foreign countries where tiles with lugs are in favor, it has been largely used on account of the cheapness of handling the tiles, and also because it is much easier to hold the tiles straight during the burning by keeping them in the block form.

Figure No. 89 shows the form in which the tiles are run from the auger machine. As the column issues it is cut into lengths suitable for the tiles, usually fifteen inches. The block is passed along to a second cutter, where wires are so arranged that they cut the false ribs, leaving a small portion at one end of each tile to form the lugs by which the tiles are to be hung to the roof. The block of tiles is then taken to the

dryer, and finally burned without separating. It will be readily understood that the portions of the ribs cut away are burned along with the tiles, but upon separating the tiles after burning, these waste strips are easily removed, and can be reground with new clay and used as grog.

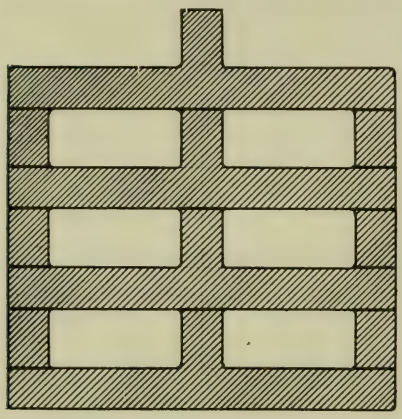

Fig. 89—Roofing Tile Bar in Block Form, with points indicated at which the cuts are made to Divide it into Separate Tiles.

This system of handling shingle tiles is better in some respects than any yet discussed, in that they are handled in large units, and will give less trouble from side checks, owing to the fact that the blocks permit a moderately open yet solid and stable setting, which will not tip or rock easily, and will permit the free circulation of the gases. Time being given for the heat to fully penetrate each of these blocks, there will be no side-checking.

By this system center marks on the tiles—that is, dark blue or black spots so often seen in the central area of tiles that have been burned too fast—when set flat or tight will be entirely obviated, because each tile is separated from its neighbor, thus allowing an easy access of oxygen and heat to the central face of the tile.

Under the heading of setting tiles it will be seen that resort to this same method has been had in part by the manufacturers of the ordinary flat shingles in this country to overcome side cracks and center markings.

It is true that fewer tiles can be set in a given kiln space, but the per cent. of firsts will be higher, due to the favorable conditions under which the tiles are dried and burned. Hence, in the long run the output is likely to be larger than in the case of tiles set flat or tight together.

Cutting Hollow Blocks Into Tiles, Horizontal Delivery.—In this system the tiles issue from the machine in the shape of a rectangular column, the sides of which form the tiles, four in number. As the column issues from the die it is cut nearly through by the small steel blades, so arranged that they cut the corners of the column. A small web about an eighth of an inch thick is left to hold the adjoining sides together. It is usually necessary to run the clay rather stiff, to prevent the block from collapsing upon being cut. This cutting is usually done straight down, and not from side to side. After the column has been cut into tile lengths, a wooden form that fits the inside opening is inserted the full length of the newly cut block. The form has a handle attached to it, whereby the off bearer lifts the block from the cutter table, and stands it on end on a pallet either on the floor or a truck. Before removing

the form, the necessary nail holes are punched by hand. The form is then withdrawn, and the block passes on to the dryer and kiln, where it is burned in its original form, that of a hollow block. After burning, the block is given a sharp tap with a hammer, when it collapses, forming four separate tiles. In this system there are no waste strips, or ribs, as in the one previously described. There are, however, some other drawbacks. First, great care in handling must be used, to prevent the collapsing of the hollow block while cutting, punching and moving it to the dryer; second, the blocks are bulky, and much space is lost both in the dryer and in the kiln, though it usually happens that much small stuff, such as hip-rolls, tower tiles and special cuts, can be nested inside the hollow blocks, utilizing much of the otherwise lost space. It is obvious that center marks will not be encountered under this system. Also, there will be less likelihood of side checks than in single tiles, because the corner is the thickest part of the block. Again, tiles burned in this manner are less apt to warp, the tiles being held fast to each other along their edges.

Vertical Delivery.—This method does not differ from the preceding except in the method of delivery.

In Figure No. 90, A represents the auger chamber, or plunger, part of the machine. The clay is first tempered in some other machine, then fed into the chamber A, where it is caught by the plunger, or auger, and forced down through the die. A pallet, B, is placed upon the platform, C, directly under the descending hollow column. As the advancing clay comes in contact with the pallet, the platform, which is delicately counterweighted, moves downward at the same rate of speed as the issue of the clay. After descending a distance sufficient to produce one length of tile, the platform stops, and at the same instant the auger is automatically thrown out of gear, which stops the flow of clay. The cutting wires, D, are a part of the movable platform, so that they are always at the proper level to cut the column of clay into the desired length without waste. At E a shoot, or waster, is made by a wire cutting off the lower end of the pipe next to the pallet. The purpose of this waster is to secure tiles of uniform length if the pallet is uneven or warped or if the lower end of the column of clay becomes upset or marred by too heavy contact with the platform on which it rests. The waste cut also assists in holding the block true during the shrinkage period while drying, serving the same purpose for which sewer pipe manufacturers put rings of wet clay under their pipes. In the case of shingle tile manufacturers, it is usual to remove the waste cut before placing the tiles in the kiln for burning.

This method is, in some respects, better than that of the horizontal delivery. First, the manner in which the form is received, direct upon the pallet without rehandling, is better; second, there is less loss from

collapsing; third, the small waste ring is advantageous in that it tends to prevent the tiles from separating or warping at the lower end upon drying.

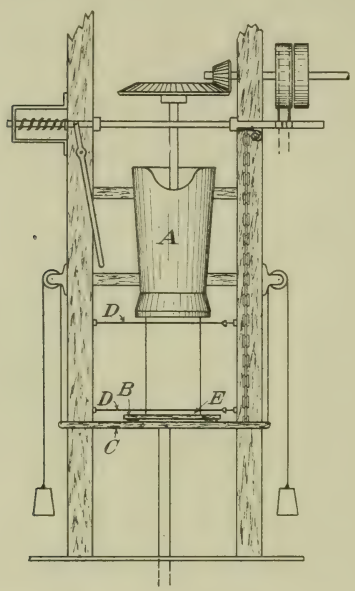

Fig. 90—Vertical Delivery of Shingle Tiles in Block Form.

There is, however, one feature that is possibly not so good as the horizontal delivery, namely, the output will be smaller, owing to the fact that the machinery must be thrown out of gear or stopped at the end of each tile length to allow for the cutting and removal of the tile, while in the horizontal delivery system the issue can be continuous.

In Figure No. 91 it will be seen that the inventor provided a recutting apparatus to cut and remove these parts of the lug strips not needed for the lugs. This he accomplished by making a form carrying four wire cutters substantially as shown in the drawing. This form was inserted in the hollow block, until the block F rested upon the pallet. The handle H was then given a partial turn, so that the arms I engaged with the springs J, which in turn pushed the cutters K outward to a position where they would cut the lug strip free from the tile. Upon withdrawing the form, the severed strips were then removed by hand. In the case of tiles with nail holes, it would only be necessary to insert a form at the upper end a short distance to hold the pipe in shape while punching.

Shingle Tiles by Power Presses.—By the use of a power press it is possible to make many forms of shingle tiles that are impossible to make on the flow die machines. The greatest difference lies, however, more in the matter of ornamentation, or outline of the tiles, than anything else.

The use of auger machinery to run out and cut off the blanks, followed by the power press to give them any desired finish, or lugs, or shape, or ornamentation, therefore constitutes the most modern and effective equipment for shingle or any kind of roofing tiles. Whatever part of the output that can be used in the form in which it comes direct from the auger machine can be so made. Where the trade demands more ornate shapes, the use of a different die and different reel cutter and power press immediately permits this line to be made also.

The best example of the press-made shingle tile is found in the plant of the United States Roofing Tile Company, Parkersburg, W. Va. This company is manufacturing a tile of somewhat unusual shape, being

patterned after the ordinary wooden shingle; i. e., thick at the butt end and tapering down to quite a thin section at the other end. The object of this shape is to allow the tile to fit more closely to the sheathing boards.

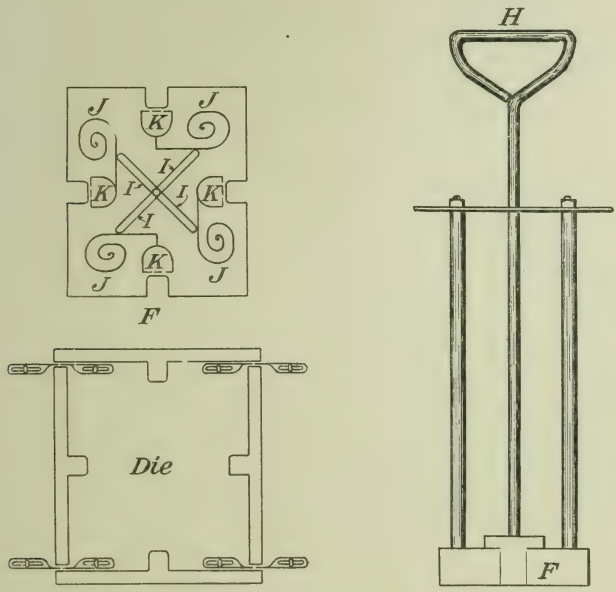

Fig. 91—The Robinski Lug-Cutting Apparatus.

Not only does the tile vary in thickness from end to end, but in some of their patterns, the monotony of an otherwise plain tile is broken by an outline of gutters and raised parts on the portions of the tile which extend from the next superposed tile on the roof. Such shapes exclude any other method of manufacture than that of pressing.

In the manufacture of these tiles, the company first runs blanks on one of J. D. Fate & Co's. combined double shaft pug mill and auger machines. The blanks are about one inch thick by five inches wide and are cut fifteen inches long by a reel cutter.

From the cutter the clay blanks are conveyed by an endless belt conveyor to the presses (see Figure No. 93).

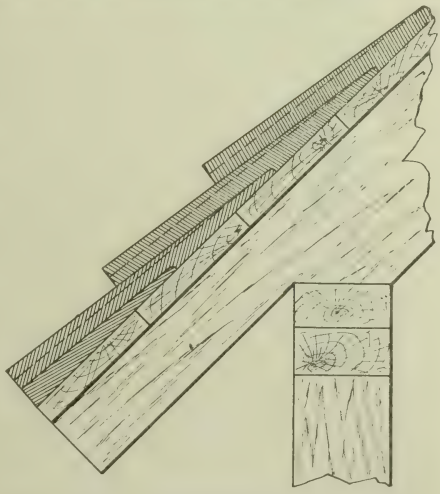

Fig. 92—Pressed Shingle Tiles made by the United States Roofing Tile Co.

Just as the blanks leave the cutter, they are coated or painted on their upper face with an oil especially made for this company by the Upson Soap Company of Parkersburg, W. Va. The oil is applied to prevent the clay from sticking to the metal dies of the press. As the blank reaches a point opposite the press, it is picked up by the press feeder (see Figure No. 94) and fed onto the nearest die of the pentagon on the press. As the pentagon of the press revolves one-fifth revolution, it brings the blank of clay under the top die where it receives a pressure that causes it to flow out and fill every part of the die box, each blank being cut to a length that is just sufficient to exactly make one tile. After the pressure has been applied, the pentagon revolves one-fifth revolution, the tailsman or off-bearer places and holds a receiving pallet on the tile, and as the pentagon moves to its next position, the tile loosens from the die resting on the pallet (see Figure No. 95). The off bearer then places the laden pallet on a rack where the tiles are examined and the nail holes punched by boys. This company is manufacturing three styles of pressed shingle tiles, one form of which is shown in Figure No. 96. Other companies are making various forms of pressed shingle tiles. Among them are the Ludowici-Celadon Company, Mound City Roofing Tile Company, Alfred Clay Company, and the Detroit Roofing Tile Company.

Shingle Tiles by the Dry Press Process.—While this fascinating method of working clay has on several occasions been tried in this country in the manufacture of roofing tiles, it has never yet proved successful. The trouble has been that the tiles could not be made dense enough to withstand the weather. In addition, the roofing tile dies are usually of complex enough shape, so that the dry powder filling the die would have a variable thickness in different parts. On the descent of the plunger, the thick part of the powder layer would be much more densely compressed than in other parts where the clay was thin. Grave irregularities of structure are thus produced, and the process is not practical. By packing the die with the powder in advance of the descent of the plunger, and cutting out the excess clay in the thick parts by hand, it is perfectly feasible to make a tile of irregular cross section and of uniform density, but the cost of hand packing the die for each tile is too great.

If any success is reached, it will be by the use of previously tempered plastic clay, partially dried, granulated, and pressed with enough water in it to make a dense body, which flows under heavy pressure and forms a perfect bond. Such a process is used in electrical porcelain manufacture, and it seems possible that it might be introduced in roofing tile manufacture, especially for the simple forms. Exactness of shape, a great desideratum in roofing tile manufacture, would be secured in the highest degree.

Fig. 93—Cutter and Tile Blanks, United States Roofing Tile Company.

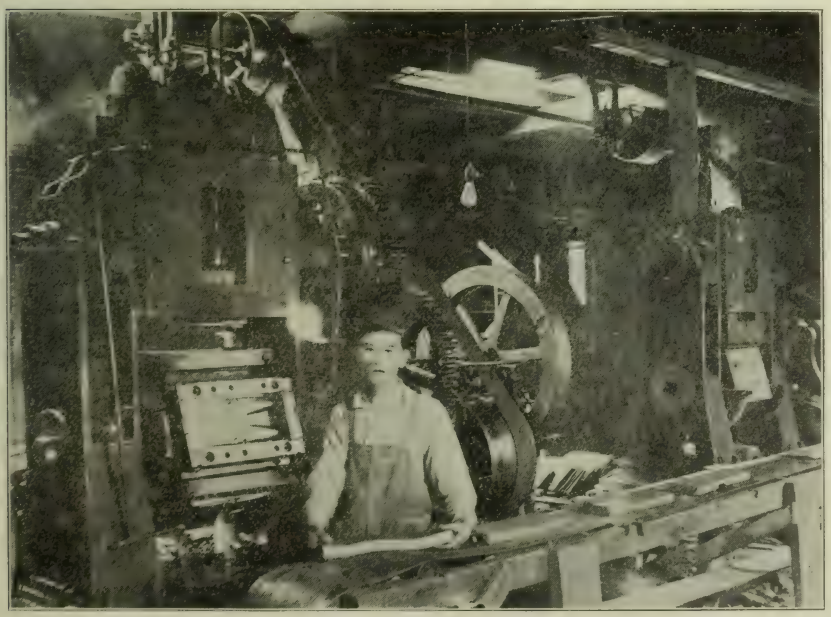

Fig. 94—Feeding Side of the Roofing Tile Press, United States Roofing Tile Company.

THE FORMING OF SPANISH TILES.

The roll tiles in their various forms have been used more widely than any other single style or shape. Among the most ancient tiles, traces of the roll or normal tiles are to be found. Their use has been not only very extensive, but satisfactory from both the artistic and practical point of view.

In the manufacture of this style of tiles in the United States, many improvements in form and methods of manufacture have been made. It is rare to see this style of tiles made in this country in any other manner than by power machinery, while in the old world many are made by hand either in plaster moulds or on hand presses.

Hand Pressing in Plaster Moulds.—In making this shape in hand moulds, it is necessary to have the clay prepared quite soft and well kneaded, with the plaster mould on a low bench or table. The presser takes up a mass of clay sufficiently large to make one tile with a little to spare, and rolls or works it into a "grub" in shape like a loaf of rye bread. This roll is then thrown into the mould with considerable force, and batted by the hand and forearm until it fills every part of the mould. The excess is then scraped off, or cut away by means of a straight-edge or wire-cutter. The necessary lugs or nail holes are made, and the inside is "slicked" with a rubber card or sponge. The mould is then set aside, until the clay shrinks loose from the plaster. The tile is then emptied out onto a pallet, while the mould goes back to the bench to be refilled.

With an ordinary granular clay, not too adhesive, that will give up its water freely to the plaster mould, from ten to twenty moulds will be found sufficient to keep one presser busy, but should the clay be extremely plastic, a much larger number will be required.

This method of manufacture is the most expensive of all, and at the same time the tiles are apt to be weak, because very little pressure can be applied in the manufacture, and the clay is worked very soft and rather lean and sandy.

Pressing in Hand Power Press.—The next method used in the manufacture of Spanish tiles is by hand-power press. While this method is perfectly possible, it is not used at all in this country, at least on regular tiles. Special Spanish tiles, like tower tiles, eave tiles, hips and valleys, etc., are to some extent made on hand presses. In the plant of the Cincinnati Roofing Tile and Terra Cotta Company, all special Spanish tiles are made on a Perfection Hand Press, manufactured by the C. W. Raymond Company, Dayton, Ohio. At the Western Roofing Tile Company, special Spanish tiles were made on a small hand press of the eccentric type. This press had been formerly used in a glass works for pressing glass and had been fitted with new dies for the clay

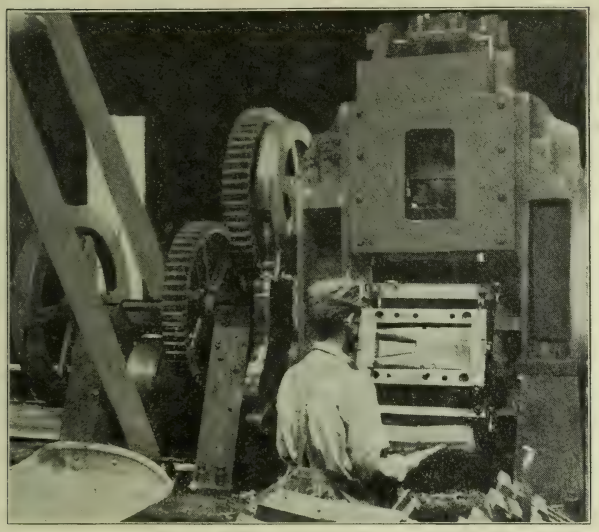

Fig. 95—Off-bearing Side of the Roofing Tile Press, United States Roofing Tile Company.

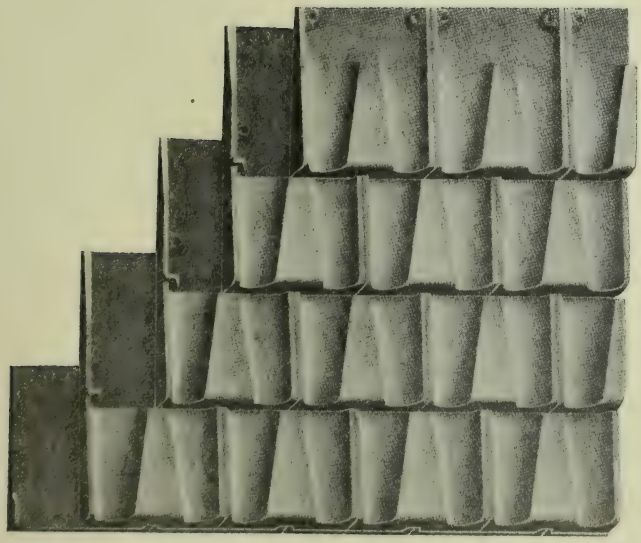

Fig. 96—Press-made Shingle Tiles, United States Roofing Tile Company.

business. The name of the manufacturer could not be obtained, but it is not important, as the machine is not regularly on the market.

Spanish Tiles by Flow Die Processes.—The simple straight "S" tiles, without lugs or interlocking features, permit the use of flow die methods, and as this method is always cheaper than pressing, it is certain to be used whenever it is available. Both types of flow die machines, plungers and augers are used.

Spanish Tiles by Plunger Machine.—The plunger machine itself has been described to some extent earlier. The only example of the use of this machine for the manufacture of Spanish tiles found in the country in 1908 was seen at the Cincinnati Roofing Tile and Terra Cotta Company, Winton Place, Cincinnati, Ohio.

At this plant, much attention is paid to having the clay well tempered before reaching the plunger machine. It is ground until it passes an eighteen-mesh screen, then enters a storage bin located on the second floor of the building. From the bin, the clay is introduced by spout into a seven-foot wet pan, manufactured by the American Clay Machinery Company.

In the wet pan the clay is tempered with water for a period of ten minutes or so, and is then unloaded onto a belt conveyor which delivers it to a hopper placed above the charging hole of the plunger machine. This hopper will hold about two wet pan charges at a time. A man is stationed at the hopper, where he feeds the proper amount of clay into the machine on each stroke by a shovel. The output of the machine depends upon the feeder, for he can, by overfeeding, cause much waste and loss to occur. In the case of the Spanish tile the amount of clay needed for each tile is, roughly speaking, about an ordinary shovelful, but as the clay is in lumps of more or less irregular size and shape, it is not always possible to feed the proper amount. In order to have a sufficient amount, the feeder feeds what he thinks will be a little more than enough.

The output for this plunger machine, under the most favorable conditions, will not exceed 5,000 Spanish tiles. More often the daily output does not exceed 3,500. With an auger machine and the same number of operatives, these figures can easily be doubled.

Cincinnati Spanish Tile Die.—In Figure No. 98 is shown a line drawing of the Cincinnati Spanish tile die. The drawing on the left represents the outward face of the die, from which the finished tile column issues. On the right is shown the rear or inside face of the die, with the beveled shoulders and the belled or coned corners, each of which is necessary to control the proper flow distribution of the clay.

The sectional drawing more clearly shows the amount of bevel on the main part of the die. The corners, however, receive a slightly greater increase of bevel.

It will be seen that this die is made in two parts, which divide at the extreme edges of the tile, as indicated in the drawing on the face side of the die. The two parts are fitted very carefully together, and are then held in that position by the two bolts, as shown.

When the die wears away, allowing the tile to come too thick, the halves are taken apart, and the points of contact dressed off until the proper thickness is again secured. By this means it is possible to prolong the life of the die very materially.

Ordinarily these dies are made of cast iron, though at times chilled iron and steel have been used. In the latter materials the dies are extremely difficult to dress or file in order to get the proper feed of clay.

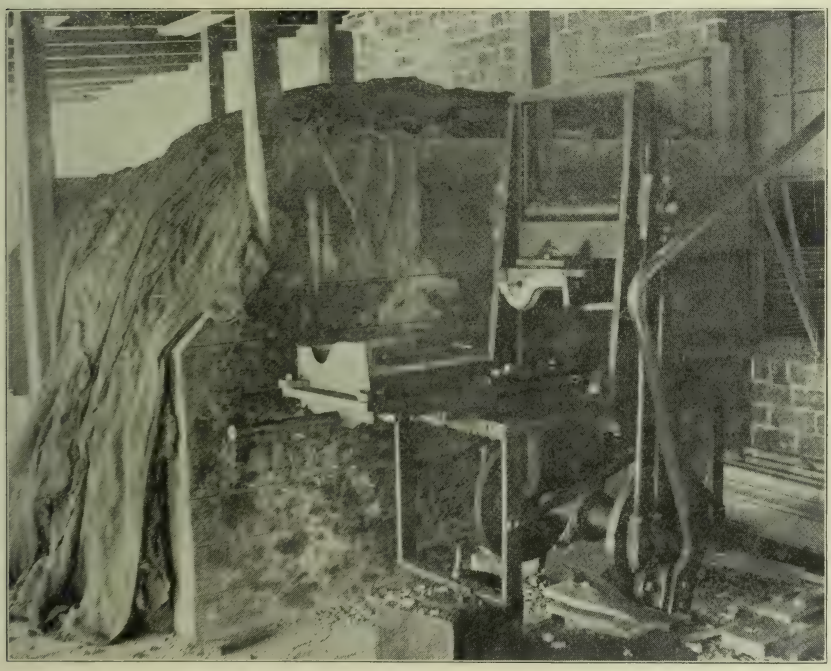

Fig. 97—Hand-power Press, Western Roofing Tile Company.

Periodic Cutters.—It will be found very necessary to have a well-constructed and accurate cutter for handling Spanish tiles. At the Cincinnati plant a cutter manufactured by the American Clay Machinery Company is being used.

Figure 99 shows the cutter in detail, except that the angle clippers are not required on the cutter as used at Cincinnati. In operation the cutter works about as follows: As the "S" shaped bar leaves the plunger, it passes over a wool-covered, oily roller, shown in cut, which lubricates the under side of the bar, so that it moves freely over the cutter table without sticking. The bar is allowed to run out until its outer end has passed the second slot shown in the cut. The lever is

then pulled down, the block A comes in contact with the top of the clay column, where it rests, while the two cutting wires pass on down through the clay into the slots. As the wires descend, the bolts, or pins, encircled by springs, descend also, punching the nail holes. The handle is now released, the counterweight raises the cutting frame clear of the tile. The block A remains on the tile until the cutting wires have cleared the clay, then the block moves up out of the way. This is done to prevent the wires, on their return through the clay, from "feathering" the ends of the tile. Immediately at the outer end of the cutter the offbearer stands with a trowel (see Figure 100).

This trowel he inserts under the pan of the tile while on the cutter table, then lightly supporting the roll of the tile with the other hand he lifts the tile from the table and places it on a pallet near by.

The work of offbearing is not only very tiresome, but very exacting as well. Much pains must be taken to see that the tiles are placed on the pallet straight, otherwise they will dry crooked, and must be returned to the dry pan as scrap.

At the Cincinnati plant the tiles are placed three deep on a single pallet. Formerly they were placed five deep, but this was abandoned.

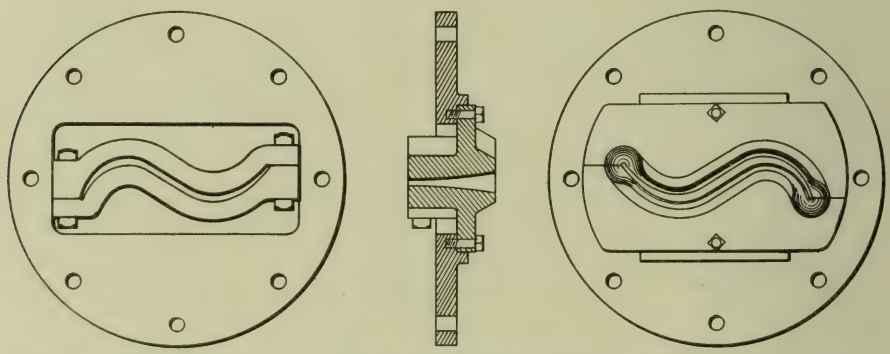

Fig. 98—Spanish Tile Die, Used by the Cincinnati Roofing Tile & Terra Cotta Company.

In Figure 101 can be seen the three tiles on the pallets in place on the truck. The pallets will be discussed under the section on dryer cars and pallets.

Spanish Tiles by Auger Machines.—The manufacture of Spanish tiles on the auger machine differs from that on the plunger machine in that the column of clay moves continuously from the auger, instead of intermittently, as from the plunger. It will be understood that with the moving bar a cutter must be provided that moves with the bar, while with the plunger machine the cutting table remains stationary, and cuts only when the bar is at rest. It would be impossible to make a straight cut through a moving clay bar unless the cutting wires were moving at exactly the same speed as the clay. The backward and for-

ward movement of the cutter does not move to exceed eight or ten inches, because ample time is given to make the vertical cut and return the cutting wires to the original position while the clay bar travels that distance. By a small lever, under control of the operator's foot, the entire table is returned to its original starting point after each cut.

At the plant of the Ludowici-Celadon Company, New Lexington, Ohio, where more auger-machine Spanish tiles are made than at all other American plants combined, it was found that they are using four auger machines of various sizes, the largest one of the four being used on Spanish tile. It is not meant by this that the particular machine in use by them is any better suited to the work than other machines of equal capacity, but it indicates the strength and power required to force clay out from so small and so irregular an aperture. The Ludowici-Celadon Company is using wooden pallets, as shown in the figure, and also places tiles three deep on one pallet. Their cutter is of their own design. In general it is not widely different from the American Clay

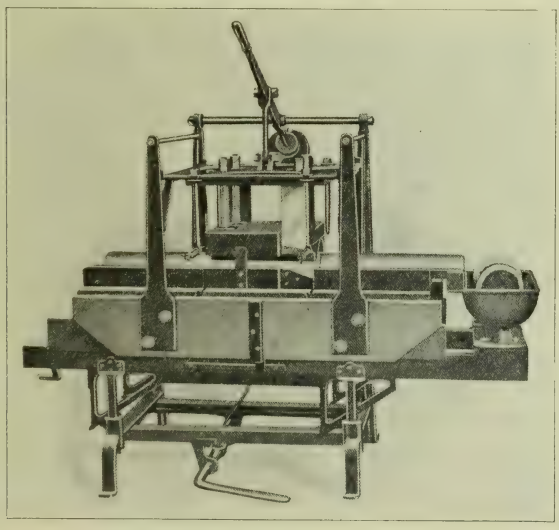

Fig. 99—Spanish Tile Cutter, by the American Clay Machinery Company.

Machinery Company's cutter (Figure No. 99), except that it is much stronger and is movable. The cutting wires pass through the tile with a downward shearing motion instead of straight down.

Spanish Tiles by Power Presses.—At the present time there is only one type of press in use for the manufacture of regular Spanish tile—namely, the revolving pentagon press.

Revolving Table Press.—A number of years ago, at Ottawa, Ill., a press of the revolving horizontal table type was used for making small-sized Spanish tiles. This press was manufactured by D. J. C. Arnold,

of New London, Ohio. Metal dies were used on this press, lubricated by a light oil applied by hand. Blanks were first made on an auger machine. These were fed, one at a time, onto the dies of the revolving table. In due time the blank came under the upper die, where it received the necessary pressure to shape the tile. The table in its next move brought the die with its newly pressed tile to the "dumper," who placed a pallet upon the tile with one hand, and turned the die half over, or until the tile loosened and dropped onto the pallet. The dies were hinged at one side to permit of dumping. To operate the press under the conditions at Ottawa three men and a boy were required—a press man, oiler boy, feeder and dumper. The daily output was from thirty-five hundred to five thousand.

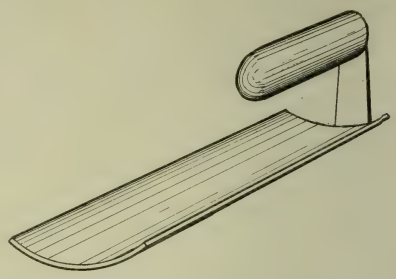

Fig. 100—Trowel Used for Removing Spanish Tile from Cutter.

This press was not a success, economically, the output being too small for the number of men employed. If it were improved by supplying an automatic dumping device and automatic oiler, it would probably be thoroughly practical and satisfactory.

There is a class of work that could be done on it cheaper than by the ordinary drop presses used on special work.

The Pentagon Press.—Five different presses of this type were found in use for the manufacture of interlocking Spanish tiles: at the Western Roofing Tile Company, one press manufactured by Crawford & McCrimmon, Brazil, Ind.; at the Detroit Roofing Tile Company, one press, manufactured by the Illinois Supply & Construction Co., St. Louis, Mo.; at the Ludowici-Celadon plants, Chicago Heights and Ludowici, Ga., presses manufactured for them in Chicago, copied from the Ludowici tile press of Germany; at the Ludowici-Celadon Company's plant, New Lexington, Ohio, presses manufactured by the Rogers Machine Tool Company, of Alfred, N. Y.

In three of the above plants, plaster dies were being used. In the other two cast iron.

The methods employed by the various plants in the production of press-made Spanish tiles are the same, with the exception of the lubrication of the metal dies.

The first step is that of producing the blank from which the tile is to be made. In every one of the above plants this is done by auger machines. The J. D. Fate Company, of Plymouth, Ohio, has five double-shaft combined pug mill and auger machines at work on Spanish blanks, and the Bonnot Company of Canton, Ohio, has one.

Neither of these companies claim that its press or auger machine is specially or exclusively for the production of Spanish tiles. They use the same machinery on any and all of the styles of tiles they produce. For instance, The Detroit Roofing Tile Company is making six or seven styles and sizes of tiles on a single press, it being customary to run a good stock of one kind of tiles, and then change the dies and run another style. Similarly in the production of blanks of Spanish tiles, the auger machine must make blanks for all kinds and oftentimes prepare the clay for the modeling floor as well. The clay coming from the pug mill or other tempering device, or if it has been aged after the tempering, coming from the cellar, is fed into the auger machine, which forces it through the mouth piece in a bar of the desired shape. In the case of the Spanish tile blanks, it is usual to have a double stream die, with two columns issuing from the machine at the same time. These streams are usually about two and one-half inches by four inches in cross section, with rounded corners. Upon leaving the die they pass under a reel cutter, which cuts the two bars into lengths of about twelve inches, which will furnish a slight excess of clay over that needed for a single tile.

As the blanks pass from the cutter, they are carried by an endless belt to the pressman or feeder. Immediately behind the feeder or a little to one side, is a low bench, upon which a boy "hacks" the blanks as they are delivered by the belt. It is usual to keep a stock of fifty to one-hundred blanks on the bench at all times, to tide over short stops of the auger machine. Before commencing work it is necessary to see that the plaster dies are well saturated with water. This being done, the feeder takes up a blank with both hands and slams it with considerable force onto the face of the die in front of him. The pentagon, making one-fifth revolution, brings this newly filled die under the top die, which descends, forcing the blank to fill all parts of the space between the top and bottom dies and squeezing out all excess clay. The pentagon again moves, the off-taker or tailsman places a pallet upon the tile, and waits for the die to reach the third position, when the tile releases very easily.

The pallet (see Figure No. 153) with its tile is then put on a belt conveyor driven from the pentagon shaft in such a manner that it moves forward about two feet with each movement of the pentagon. Thus, between intervals, the edges of the tiles are "skinned," or trimmed by boys or girls, one on either side of the belt. It is usual to have another known as the "puncher" whose duty it is to punch the nail holes, or to perforate the small lug on the under side of the tiles by which they are wired to the roof purlins. Another boy or man is required to take the tiles from the belt after they have been trimmed and put them into the dryer cars.

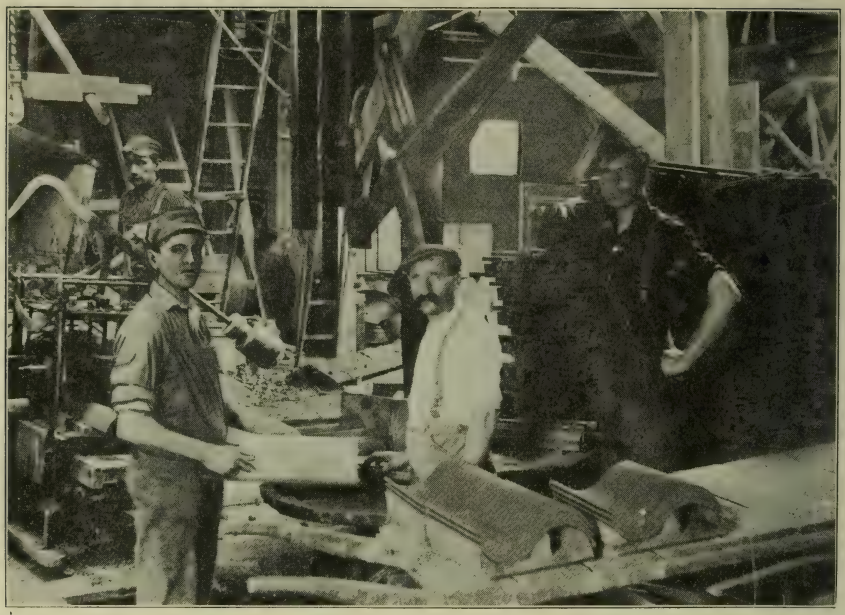

Fig. 101—Plunger Machine Making Spanish Tiles, at Cincinnati Roofing Tile & Terra Cotta Co.

Fig. 102—Tiles Delivering from Press. Detroit Roofing Tile Company.

The output of Spanish tiles on a pentagon press will run from four thousand to six thousand per day. The latter figure can seldom be attained.

Lubrication of Dies.—Where metal dies are used for Spanish tiles, it is necessary to keep the dies hot to assist the clay in releasing. This is done in one plant by steam, which passes directly through the backing of the die. At another natural gas flames were used, the flames coming in direct contact with the face of the dies. The oil used for lubrication was the Atlas press oil, made by the Standard Oil Company.

Where steam was used to heat the dies, the oil is sprayed onto the dies by compressed air. In the other plant the under side of the blank was oiled by passing over a wool-covered roller, which was dipped in oil. Instead of oiling the upper face of the blank the oil was applied to the top die itself by hand.

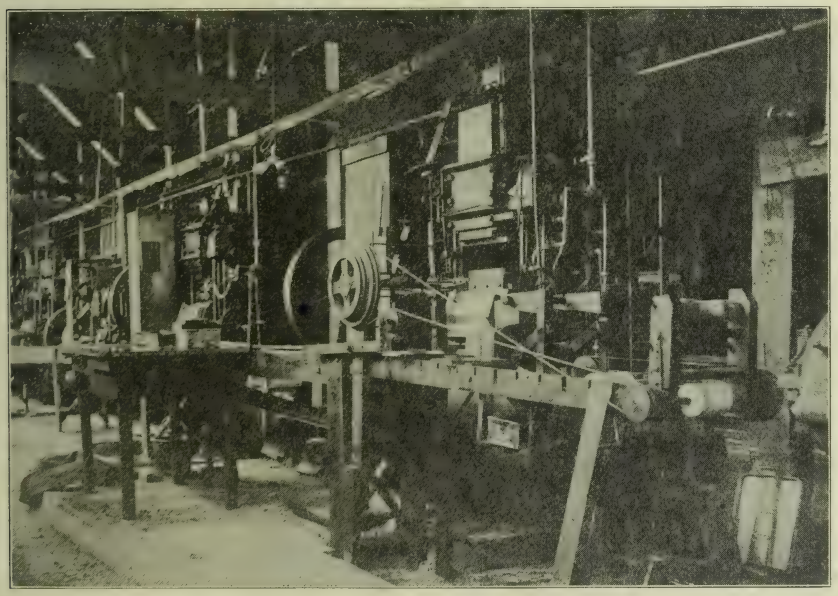

Fig. 103—Home-made Reel Cutter for Cutting Blanks. Ludowici-Celadon Co., Alfred, N. Y.

FORMING OF INTERLOCKING TILES.

The interlocking tiles in this section refer to the regular interlocking tiles of commerce, such as those known as the French A, T-1, D-1, etc., manufactured by such firms as the Ludowici-Celadon Company, The Mound City Roofing Tile Company, The Detroit Roofing Tile Company, The National Roofing Tile Company, The Alfred Clay Company and others. It must also be understood that these same companies manufacture interlocking tiles of both the shingle and Spanish varieties, and various other patterns already discussed. These forms of interlocking tiles are becoming the most widely manufactured

at the present time in this country, if not in the world. This is due to the universal use to which they can be put; that is, they can be applied on almost any kind of roof construction, such as open or closed construction, either wooden or steel. They are considered the cheapest tiles to manufacture per square, on account of their large size, can be sold at the lowest price, and are the cheapest to apply. Hence, it is easy to see why they are so popular. With the use of proper principles in designing the locks they also make one of the best roofs.

The methods of manufacture in the various plants are but slightly different. In every case the blanks are made on auger machines, which are undoubtedly the most efficient for this work. Of the various auger machines found in use for this work, there were six plants using Fate machines, one plant using a Bonnot machine, and two using the American Clay Machinery Company's machines.

Shape of Blanks.—As to the shape of the blank, six of the plants are running bars of about two and one-half inches by four inches, which are then cut into suitable lengths, about fifteen inches, by reel cutters of the type to be seen in Figure No. 103.

These bars are made both in single stream and double stream dies. There is something to be said for the double stream die here, which perhaps does not apply with equal force where it is expected to use the bar after cutting as a finished product, viz.: the die pressure is much less, and the power required to run the auger machine is materially decreased. Since the blank undergoes a complete rearrangement in pressing, any faulty structure, if any exists due to double stream dies, is eliminated. On the same reasoning a side-cut brick die and cutter could be used equally well, with still less die pressure, but no instance of this was found. It is possible that the wire-cut surface of the side-cut brick might still persist in some degree after pressing, which of course would not do.

At two plants the blanks are run with outlines conforming to those of the tiles to be made. The blanks have the side-tongues and grooves, and the press then only has to form the head and heel locks.

As to the relative merits of shaped vs. unshaped blanks, it can be said that where plaster dies are used, the thick two and one-half inch by four inch block form is the better. The die fills better if the clay has to flow vigorously, than if the blank is nearly shaped in advance, and changes shape but little in pressing. Also, the tiles seem to release from the die with less trouble where the clay flows, than when fed in pre-shaped blanks.

In the case where metal dies are used, the reverse is certainly true. With metal dies, oil must be used to prevent the clay from sticking. If the clay has to flow vigorously under pressure in the die, it will scour the oil from the metal, leaving the surface bare in the central part, where the flow has been longest kept up. The tile will then stick

in the center. Also, the oil that has been pushed along ahead of the clay enters the tongue grooves, and prevents the clay from properly filling them.

It will thus be seen that it is better to run the blanks for metal dies of approximately the same outline as the finished tile, leaving the work of the press as light as possible.

The mere forming of the end locks does not cause any extensive motion of the main part of the clay and hence the oil is not disturbed, and still acts as a separating medium between the metal and the clay. Each form of blank therefore has its proper place, depending on the kind of die used. There is one objection, however, to the plan of running blanks of a shape to conform to the tiles, viz., it is not possible to store very many of them in advance owing to their thin section and the ease with which they dry out and are broken. This requires the auger machine to run almost continuously to supply the blanks as needed.

In the case of the simple rectangular blank, large numbers of them can be piled up ahead of the press consumption, thus making it possible to change dies on the auger machine and run other kinds of ware a part of the time. In plants of moderate size, this latter point will be found of considerable weight.

Pressing.—The pressing of the interlocking tiles is not different in any but the most trivial details from the pressing of such tiles as have already been discussed, and no further time need be spent on it at this point.

Forming Interlocking Tiles on the Auger Machine.—There is a great field for the introduction of interlocking tiles made on the auger machine in this country, which is not receiving as yet any attention. Not a single plant in this country is making tiles of this kind at the present time, and only one instance was found where work along this line had been done in the past.

Just why our tile manufacturers have not taken to the auger-made interlocking tiles can only be surmised. Foreign roofing tile makers have for many years seen the possibilities of the auger machine on this class of goods, and have perfected many ingenious devices in the matter of dies and cutting tables to properly form the bar and cut it into interlocking tiles.

In the nature of the case, it is only possible to run the locks along two parallel sides of the bar. If side locks were made by the flow die, the end locks cannot be made, and *vice versa.* It is quite probable that the lack of end locks has been the objectionable feature of auger-made interlocking tiles which has prevented their adoption in this country. This objection has weight, of course, but not more weight than it has in the case of auger-machine Spanish tiles, so popular at the present time.

By laying such tiles on closed-roof construction, with roofing proper beneath, they can be made to give satisfaction. No one would think of applying the auger-machine Spanish tiles on an open construction roof, i. e., on purlins only; neither should anyone think of so doing with the auger-machine interlocking tiles. The auger-machine interlocking tiles provide a cheap material for cheap structures, a field that is only occupied at present by the culls of the other styles of tiles. Any one undertaking to enter a cheap auger-machine interlocking tile into the field of the pressed variety would unquestionably fail in his attempt.

The firm that at one time made interlocking tiles on the auger machine was the Ludowici Celadon Company, at their New Lexington plant. The tiles as manufactured by them were of such a cross section that the under side of one tile would fit the lines of the upper side of the next below.

One style of auger-machine interlocking tiles does provide a partial head lock. These tiles are made from a rectangular pipe, the two interior faces of which are separated by some little space. After the bar has been cut into lengths, as shingle tiles are cut, it passes to a second cutter, which notches out the ends of the tiles as shown in the cut below.

These notches allow the lower end of the upper tile to lap over the upper end of the lower tile, thus making a partial lock.

Plaster Dies vs. Metal Dies.—The first use of plaster of Paris for roofing tile dies dates far back into the past. It is doubtful whether any material will ever be found to supplant it. At least on most clays it is the only material that will give a perfect tile. Metals of various kinds have been tried, and are being used at the present time, but no single case has yet been seen where tiles made on metal dies are free from flaws and checks due to the necessary use of some kind of lubricating oil. With tiles from plaster dies, this cannot be said.

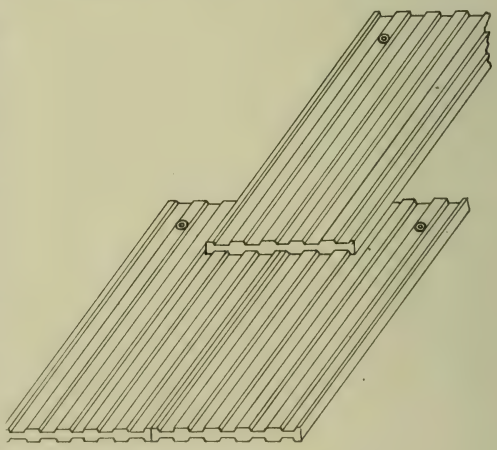

Fig. 104—New Lexington Auger-made Interlocking Tiles.

By analyzing the conditions in the two cases, it will be clearly understood why the above is true. 1st, with plaster dies, it is necessary to work the clay softer than with metal dies; 2nd, plaster dies are necessarily kept saturated with water. With metal dies, their surface must be oiled with a heavy oil. When a blank is fed onto either kind of die,

and the pressure is applied, the blank is squeezed very quickly down to the thickness of the finished tile. In undergoing such a radical change of shape, many small checks and seams will infallibly develop. On the plaster die, which is saturated with water, the water will find its way to these newly developed checks, softening their edges and helping them to mend or unite while under pressure. In the case of the metal dies, the oil used for lubrication will enter the checks just as the water does with plaster dies, but instead of assisting them to knit, they are prevented from doing so. There may be certain clays, high in free silica, which would prove an exception, but for fat, plastic clays, such as roofing tiles are usually made from, the above certainly holds true. The fat clays work much the best on plaster dies. Another fact comes into consideration in this connection, viz., the clay must be in a markedly more plastic condition for forming on plaster dies than for metal. This assists powerfully in preventing as well as in mending checks or flaws.

On metal dies, the stiffer the clay can be worked, the better it will release from the die, but the more numerous the checks will be. It is true that metal dies are being used with more or less success on some clays. What the properties of a clay are which determine whether it can be successfully worked on metal dies or not has never been satisfactorily worked out.

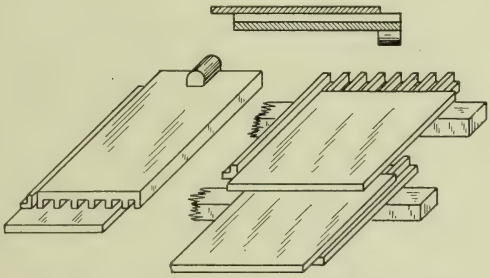

Fig. 105—Auger-made Interlocking Tile.

Roughly speaking, the more plastic, fine-grained clays, low in gritty substances, are best suited to plaster dies, while clays of the opposite physical properties are best suited for metal dies. The strongest objection to plaster dies is that they are expensive to keep in repair. It is necessary on most clays to renew them every day. Top dies are often renewed twice per day.

To keep this work up requires the work of one man and a helper in a five-press plant. The same workman, however, also makes all the plaster dies needed about the plant, such as crestings, hip-rolls, copings and special pieces. Every roofing tile establishment has to be able to meet calls for these ornamental pieces, and at least one plaster worker is a necessity, anyhow.

The plaster of Paris used should be of a good grade, and should be very finely ground for the best results. The average price per barrel of suitable plaster is from $2.25 to $2.10, or often less when bought in carload lots.

Making Plaster Dies.—The art of making plaster dies for roofing tiles is by no means a simple thing. Much experience is required to work the plaster so that when cast the resultant dies will not be full of air-blebs, known to the trade as "rat holes." If blebs appear on the surface or in the body of the die, the plaster will have to be chipped out and the casting remade.

To make the die, three parts are required, the upper and lower die shells and the tile matrix.

The shells are cast iron boxes, made to conform roughly to the shape of the tile. They are made about one-half inch longer and wider on each end and side than the tile. and about three-fourths inch deeper than the thickness of the tile. The thickness of the iron in the shells is usually about three-eighths to five-eighths of an inch on the sides and three-fourths of an inch for the bottom.

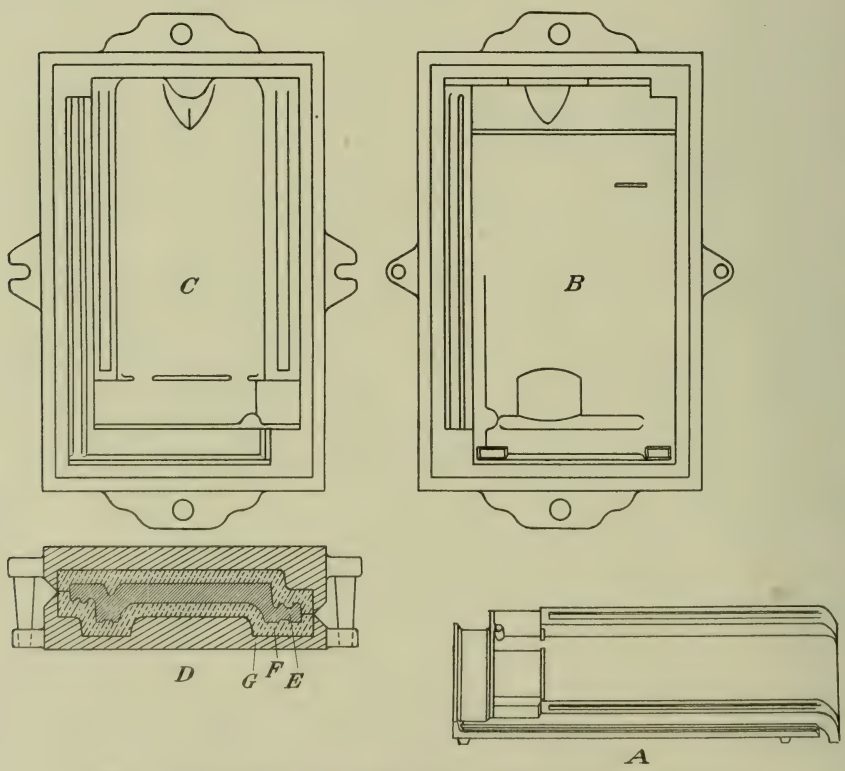

Fig. 106—Die Shells and Matrix for Making Plaster Dies.

In Figure No. 106, A represents the matrix of the tile. This matrix is an exact pattern of the tile to be made. It is usually made of cast iron—though aluminium is better—and is finished off perfectly smooth and to size, with dividing lines on the sides and ends to mark the depth to which the matrix is to be set in the die shell when casting new dies.

B and C represent the upper and lower die shells, with the plaster in place. D shows a cross section of the dies when pressed together. E represents the clay necessary to form the tile, shown by the heavy shading. F represents the plaster facing of the die, and G the cast iron die shells. Assuming that the new die shells are to be lined with plaster, the steps to be taken are as follows:

First. Swing or adjust the matrix to its proper level in one of the die shells. This is done by blocking it up on small pieces of wood to about the proper level, and then adjusting it by small pats of clay on the top of the wooden blocks. The matrix is then tapped with a mallet until it takes a good bearing and is on the right level.

Second. The space surrounding the matrix and separating it from the shell is now filled in with plastic clay. When filled, it is carefully smoothed and finished so that it coincides with the line of the matrix.

Third. The upper surface of the matrix is now painted or coated with a dressing called "dope," composed, as a rule, of soap and some sort of fat, preferably lard, boiled in water to a creamy consistency. In some cases paraffin dissolved in kerosene oil is used. Each plaster worker has his own preparation, which he thinks is best. One receipt runs:

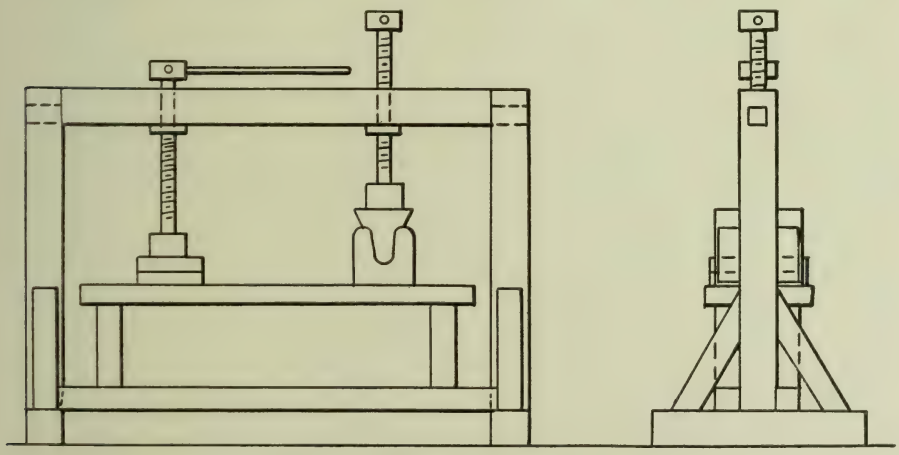

Fig. 107—Press for Plaster Dies.

For four pounds of soft soap, boiled in four gallons of water, add one pound of tallow, and stir thoroughly. In any case the function of this dressing is to keep the plaster from adhering to the surface of the matrix. It is always of a greasy nature, but the use of a greasy soap solution seems usually preferable to the use of oils direct. This dressing is applied to the matrix face, and rubbed off until it has just a thin film left upon it.

Fourth. Preparation of the plaster is next. Should the die require one pailful of plaster, take between one-third and one-half pail of soft

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tepid water, and sprinkle handfuls after handfuls of loose, fluffy plaster, free from lumps, into the water. This must be done somewhat slowly—not much faster than it will sink beneath the surface of the water. Continue to sift plaster with the hand into the water until the plaster appears to build up in a cone above the surface and only a narrow ring of water is showing around the edges of the cone. This is allowed to stand for a few moments, sometimes for several minutes. The plaster and water are now to be worked and stirred with the hand, first seeing to it that all parts of the mixture are free from lumps. By a peculiar twist of the hand and forearm, the plaster can be made to boil up, so to speak, from the bottom of the pail to the top. This working of the plaster allows entrapped air to escape, and must on no account be done in such a way as to churn more air into the mixture. The stirring continues until by the feeling of increasing density, or viscosity, and also of warmth, the plaster worker knows that it is time to cast.

Fifth. Carefully coat the surface of the matrix with a layer of plaster to the depth of about one-half inch. Be very careful not to entrap any air bubbles on the face of the matrix under the plaster. The balance of the plaster is now poured into the empty upper die shell. At the moment when the plaster assumes sufficient set so that it will not fall out of the shell, the upper shell is turned over onto the lower one. Then slip the two cases under a screw press, and bring a pressure to bear until the two shells meet at their parting lines. The excess plaster escapes. In ten or fifteen minutes the screw is released, and the dies taken out and separated. It usually happens that the matrix will adhere to the newly made die. If so, it is gently loosened, but not removed.

Sixth. The lower shell is now cleaned of the clay used to hold the tile matrix in position, and is placed ready for its charge of plaster. The matrix and the exposed parts of the newly made upper die are now coated with "dope." Another pail of plaster is prepared, and the work repeated. When taken from the screw press, the shells are opened, and the matrix is carefully removed from the last made die.

Seventh. The dies are now allowed to stand for some time—a half day if possible—and then, before using, they are placed in a tank of water and allowed to soak up all the water possible. This takes ten or fifteen minutes, sometimes more, depending on the hardness of the plaster.

The hardness and strength of the cast die varies with the density of the plaster or in other words with the lack of porosity, produced by working all the plaster possible into a given quantity of water. Plaster made up with the minimum of water consistent with full hydration and application is called "strong" plaster and is relatively dense. When as much water is used as will permit the plaster to set, a spongy soft cast is obtained and is called "weak." Both kinds have their particular

field. For instance, in dies, it is desired to have a die that will stand wear or abrasion, and it is not necessary for the plaster to absorb much water. Therefore, in dies, the plaster should be strong. At times it has been recommended to use lime water, that is, calcium hydrate solution, in the working of the plaster dies, to harden them. Shellac or gum, as used in stucco work, has also been tried, but the hardening of the die must not be carried too far, or the clay will stick to it instead of releasing as it will from a die of moderate hardness.

For plaster molds to be used in hand pressing, it is desirable to have the water absorb water from the clay rapidly. Hence, the plaster is worked with more water, producing a relatively weak or porous mould. The foregoing process represents the common one in use in renewing plaster dies.

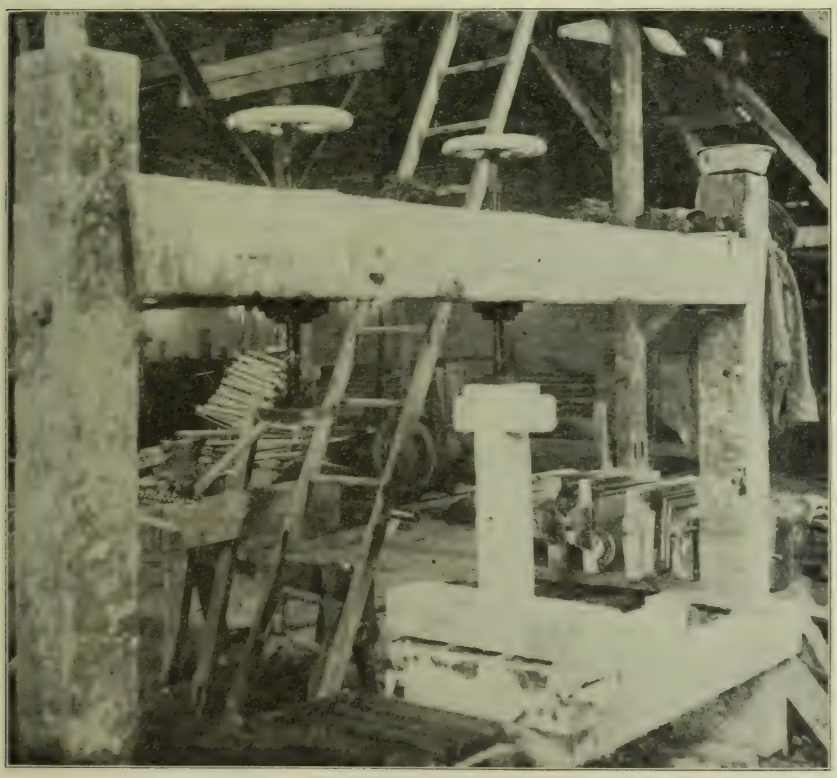

Fig. 108—Press for Plaster Dies at Detroit Roofing Tile Company, Showing Mold in Position.

Iron Master Moulds.—A better process for the renewing of worn out plaster dies is to use master dies or moulds of iron or steel, from which the real dies are made. A master die or mould is the cast or impression taken from a die with a tile in it. With dies thus made of both the

upper and lower surface of the tile, it is only necessary to spread plaster on the face of the master die, fill the empty die shell and press the two together, instead of having to build up the empty die shell with blocks of wood and clay and to adjust a loose matrix in position each time. The use of master dies is to be strongly recommended, not only from the economy in labor, but because more accurate and better dies can be made.

CHAPTER VI.

THE MANUFACTURE OF SPECIAL SHAPES AND ROOFING TERRA COTTA.

In no other line of structural clay ware manufacture is so great a variety of shapes required as in the roofing tile industry, excepting the manufacture of building terra cotta. In the latter, the use of stock patterns is very limited, and the manufacturer expects to make a complete set of moulds for each separate job he undertakes. As all of the decorative work of a building in which terra cotta is used is usually executed in this material, the number of special moulds which are made to be used once only is extraordinarily large.

While the body of any tiled roof is covered with stock tiles of one shape, there are nevertheless an endless variety of shapes to make for trimmings and for adjustments between different parts of a complex roof, and these have to be in various sizes and various pitches to fit the angle of the roofs. Then, too, the roofing tile manufacturer is called upon to cover towers of every conceivable size and outline, so that the outlay for dies and moulds represents an important part of his necessary investment and one which is never completed. As long as he is in the business, so long will his stock of moulds and dies grow. It is of course impossible to describe all of this ever changing medley of shapes and sizes. There are, however, certain kinds of fittings that are very commonly needed and these will be taken up one by one.

Hip and Valley Tiles.—The only style of roof which does not require either hip or valley tiles, or both, is the perfectly simple variety, composed of two rectangular planes intersecting at a straight ridge-line, and finished at the ends with gables. All other roofs must have tiles specially cut to fit the angle of the hips or the valleys. In most instances this cutting is done at the plant, while the tiles are still in the green condition. In rare instances, with soft tiles, especially of the shingle pattern, the burnt tiles are cut at the roof, as slate is done.

It will be understood that where there is a hip or valley to fit with tiles, it has two sides and therefore requires "right and left" hip or valley tiles. The number of lineal feet of hips and valleys that has to be cut in covering an average dwelling house roof runs into a hundred or more. Hence each roofing tile plant makes provision for executing this kind of work rapidly, though in some of the smaller plants the work is not done as cheaply as it could be by having the proper facilities. The work is charged for by the running foot, in addition to the usual cost

per square for the tiles. The method pursued at the best equipped plants is to have a "laying out floor," usually on the second floor of the building. The angle of the hip or valley is obtained from the plans furnished by the architect. All orders at modern roofing tile factories in this country are executed from plans for each separate job, and not by selling tiles by the square, or thousand, to be applied by the purchaser to suit himself. It is very unusual to sell from stock, unless for small and very simple orders.

After obtaining the angle from the plans, a base line is struck on the laying out floor to represent the eave line of the building. The length of the rafter is then measured off at right angles to the base line, a nail or spike being driven into the floor at the apex or end of the rafter, and also at the point on the base line from which the rafter was measured.

A protractor with its straight-edge set at the given angle is now moved along the base line, either to the right or left, as the case may be, to a point where a taut line fastened to the nail at the upper end of the rafter coincides with its straight edge. A nail is driven into the base line at this point, and a line is stretched from this point to the top of the rafter, high enough above the floor to allow tiles to slip in under it without touching or moving it. Taking tiles which have stiffened somewhat till they have reached the "leather-hard" condition, the cutter proceeds, beginning at the base line and the intersection of the hips, to lay up a section of tile roof. Each tile is laid on the floor, as it would be on the roof, and under the stretched line. It will be found that the line will cut each tile in a different place, until after a number have been passed one is found which is cut in the same position as the first. This is known as a "repeat," and recurs on a certain number of courses, depending upon the angle. Sometimes the repeat will begin on the sixth course, and again it may not occur until the twentieth or even more. Of course the next tile succeeding the first "repeat" is a duplicate of the second tile, and so on until another "repeat" occurs. When a "repeat" is found, it matters not whether the hip or valley is forty or a hundred and forty feet long, it is only necessary to measure how many feet of the hip are covered by the distance from one repeat to the next, and then to divide this amount into the total length of the hip to be covered, and to cut the necessary number of sets of "repeats." The tiles are cut along the line by a sharp knife, and as they are taken up from the floor, they are numbered as to their position in the set, and marked "right" or "left" as the case may be.

With one set of tiles properly cut for the angle as a pattern, it only becomes necessary to make from lath a set of angles which will coincide with the cuts on the pattern tiles. Then with a stock of leather-hard tiles and a thin-bladed case knife, the cutter can prepare and number the required number of pieces of each sort, for as many sets as are needed. In case hip tiles are being cut, the lower end of the tile only

is saved; if valley tiles, the upper end. It often happens, however, whe e there are hips and valleys in the same roof, that one cutting can be made to serve both, by saving each end of the cut tile. In this case they should be cut only part way through, and burned as one piece and then broken apart.

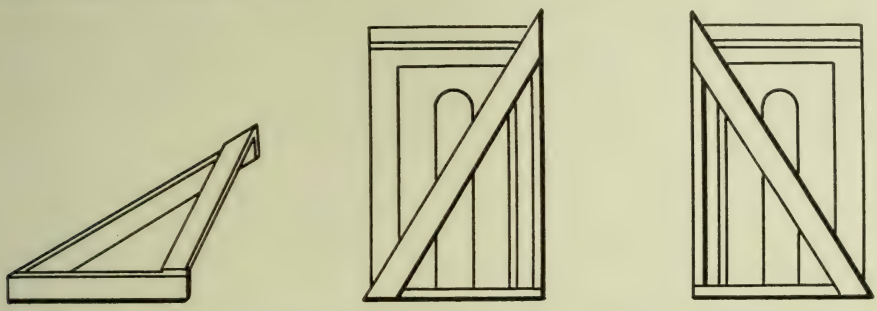

Fig. 109—Angle Frames for Cutting Hip and Valley Tiles.

As before stated, some of the larger and more up-to-date firms have other and better means for doing this work. At the plant of the Detroit Roofing Tile Company, they employ an outfit shown in the following illustration:

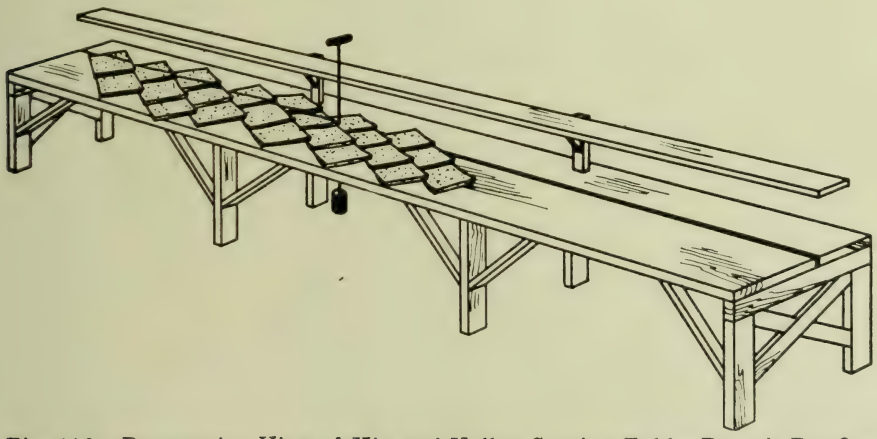

Fig .110—Perspective View of Hip and Valley Cutting Table, Detroit Roofing Tile Company, Detroit, Mich.

This table is made of planks, and is about thirty feet long. Extending along the back side, shown clearly in the end view, is a guide rail, raised about fifteen inches from the table top. Directly parallel with this guide rail, and cutting through the table top for its entire length, is a narrow slot, through which a piano wire passes, with a weight attached to its lower end, and a wooden handle at its upper end. A number of one-inch by two-inch cleats are provided, shown under the tiles on the top view of the table. The slot in the table top represents

the axis of the hip or valley to be cut. The cleats are tacked onto the table top at the proper angle to represent the purlins of the roof.

In operation, a string of green tiles is placed in proper position along and over the slot as though it were on the roof. Should the hip line be twenty-five feet long, the string of tiles is made of that length. The operator then gets up on a walk at the back edge of the table, and grasping the wire by its handle, he raises the weight from the floor, thus bringing the wire under tension. He then proceeds to move along the walk, allowing the wire to drag along the edge of the guide rail from one end of the table to the other, cutting the tiles as it goes. After the tiles are once placed in position on the table, it only takes a minute or less to cut the entire lot. If cut by hand, as described earlier in this chapter, it would require an hour or two to do the same with much more likelihood of making errors.

The cleats representing the purlins of the roof are changed from time to time, as the angle of the hip or valley may require. In cutting rights after lefts, the direction of the cleats is reversed.

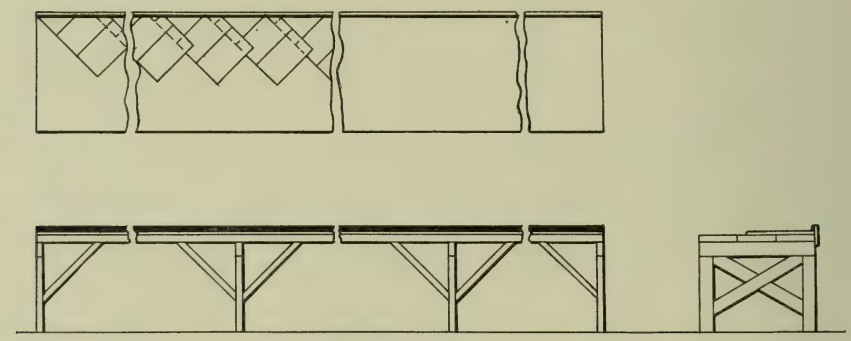

Fig. 111—Table for "Closing" Hip and Valley Tiles, Detroit Roofing Tile Company, Detroit, Mich.

"Closed" Hip and Valley Tiles.—It very frequently happens that it is desirable to have the cut ends of hip and valley tiles closed to prevent the snow and rain from blowing back underneath the tiles. This work, as in the case of cutting ordinary hip and valley tiles, is charged for by the running foot. Before a hip or valley tile can be made with a closed end, it has to first be cut to the proper angle as though it were to be used in the regular way. The ends then may be closed by plates of clay welded on by hand, or by an arrangement for closing a large number at once. The Detroit Roofing Tile Company has in use a table of about the same dimensions as their cutting table; the top is solid and is provided with a facing-board along one edge, which extends up at right angles to the top to a height of three or four inches, depending upon the tiles to be operated upon.

The tiles previously cut to the proper angle on the cutting table are placed in turn in their proper order upon the closing table, the cut end being placed against the back board, as shown in the illustration. The tiles are laid face up for hip tiles and face down for valley tiles. The operator then takes a scarfing tool and proceeds to roughen a strip of the face of the tiles about three-fourths of an inch wide next to the backing board. He then slushes the newly roughened surface with water or clay slip, to make the surface weld easily. A long strip or roll of clay of the proper temper is then placed against the backing board and brought into contact with the prepared ends of the tiles, and welded under pressure of the fingers. The entire table full of tiles is done at once, and as if it were a single tile. After smoothing up the work the operator carefully cuts the backing strip between each two tiles, disengages them from each other, trims and smooths the lower surface of the joints; the tiles are then placed on pallets ready to go to the dryer. Each tile is given its designating number and letter, as well as the order number, so that it may be identified on its way through the plant and at the roof when ready for application.

Much of this kind of work is still done in the slow and costly hand-mould process, in which moulds cut to the proper angle are used, upon which the tiles are placed one at a time and filled or closed by hand labor entirely.

Ridge and Eave Tiles—Most tiles, such as the various forms of Spanish and interlocking, require a special starting tile at the eave line, and a finishing tile at the ridge, to make a proper appearing and a well fitting roof. Spanish tiles, for instance, if left open at the bottom, provide a series of holes or openings which are speedily utilized by birds, bats and vermin in which to build nests, and which also give rains a chance to beat in.

In the Orient advantage has been taken of these closed eave tiles to apply decorations in the shape of fancy ends, or "out looks."

In our country, the closing of eave tiles has been treated as merely a business necessity, and no attention has been paid to using this feature for any decorative purpose, though rich ornamentation can well be used. The architects of this country have thus far overlooked this opportunity, but if they make a demand for fancy eave starters, which can at the same time be made to serve as snow guards, the manufacturers will surely meet it.

The greater part of closed eave tiles are made either upon hand presses or the power pentagon press, using plaster dies. In some of the smaller plants, machine-made tiles are dropped into plaster moulds and the ends put in by hand, but this method is far too slow.

The Cincinnati Roofing Tile and Terra Cotta Company, has devised an eave closer, as shown in Figure No. 115. It is nothing more than a small separate piece of tiling, made to insert under the hollow of the

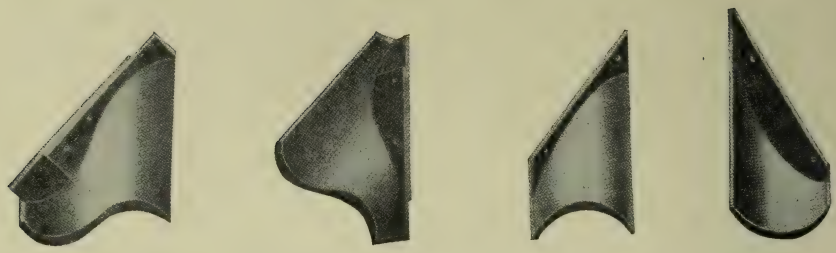

Fig. 112—"Closed" Hip Tiles.

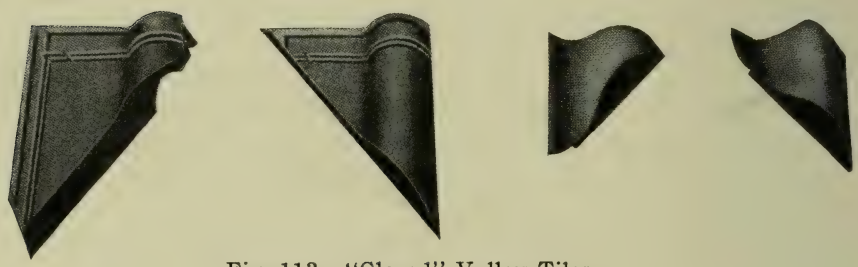

Fig. 113—"Closed" Valley Tiles.

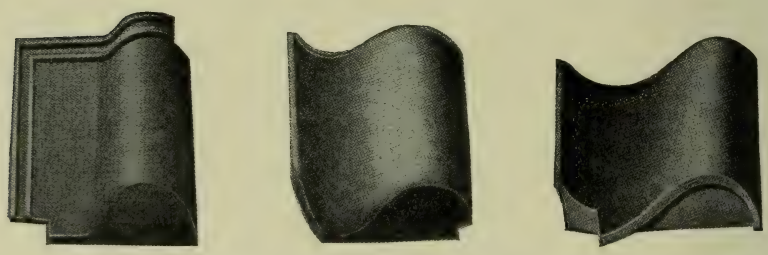

Fig. 114—"Closed" Eave Tiles.

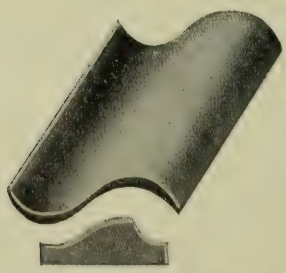

Fig. 115—Cincinnati Roofing Tile Company's Closure for Eave Tiles.

eave tile, and tacked in position with nails. While this closer can be set back under the tile far enough to give a strong shadow line, its use cannot be recommended, on account of the method of fastening. It is nailed to an eave strip, which extends with the eave line and under the first row of tiles. It is only a matter of time until the nail heads rust or corrode away and the end piece falls out and is broken and the roof is left open.

Ridge or "top" tiles are the same as regular tiles, except the upper half is flattened to a plane, which rests upon the sheathing boards, and is in turn covered by the cresting or ornamental finishing tiles. These flattened tiles leave no openings to be filled with cement, as would be necessary if ordinary tiles were used. In other patterns a flange is attached to the upper end of the tile (see Figure No. 116).

These tiles, like the eave starters, are made largely by hand presses, but in some cases by the power presses. A press that is used on this class of work is that of the Illinois Supply and Construction Company, of St. Louis, Mo. (See Figure No. 72 for description.) The Raymond Perfection hand press has also been used largely on this class of work. (See Figure No. 120.)

With shingle tiles, the cutting of hip and valley tiles is quite often done at the roof by the roofer, it not being much more trouble to cut them than it is to cut slate. Top and bottom tiles are, however, cut at the plant, the former being six inch by nine and one-half inches and the latter six inch by seven and one-half inches. These sizes are cut by the reel cutter, so that extra charge is not made for them.

Hip Rolls and Cresting.—To properly cover a roof and have all parts weather proof, it is necessary to make shaped pieces curved or otherwise to fit over the ridges and hips. These forms are called crestings or ridgings, and hip rolls. The forms of these coverings can be made very plain or highly ornamental, as shown in the following illustration:

It will be seen that many of the cresting forms must be made to fit the pitch of the roof, while others will fit any angle or pitch. The same is true of the hip rolls.

There are many forms of hip rolls that are made by hand in plaster moulds. Each plant, as a rule, has one man that models all new designs and then makes the working moulds for the pressers.

The clay used in this pressing or "terra cotta work" is usually specially prepared; that is, it is pugged by itself to a much softer condition than the regular clay for the machines, and in clays that have a high shrinkage it is very often diluted by "grog" or "grit." This material is made of broken and cull burnt tiles and kiln waste, ground and screened to about the same fineness as the rest of the clay. The amount used is from twenty-five to fifty per cent. This mixture, after being thoroughly pugged, is carried or conveyed to the pressing

floor, where it is stored in bins holding from one to two weeks' supply and kept well covered and frequently sprinkled with water to prevent drying out on the surface.

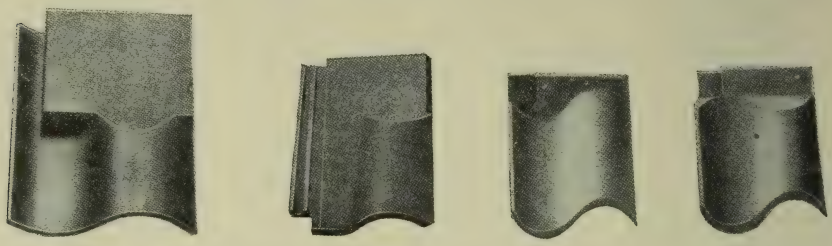

Fig. 116—Ridge or "Top" Tiles.

The operation of pressing in plaster moulds has been described before, and is substantially the same for wares of all sorts. A good presser will turn out in the neighborhood of 100 pieces of ordinary hip roll per day, but the more complicated ones take more time. It requires from six to twelve moulds to keep a presser busy.

Fig. 117—Section of Shingle Tile Roof Showing Top and Bottom Tiles in Place.

The greater part of the hip rolls and crestings at the present time are made either on the drop power-press, or the various makes of hand-presses, and in most cases it will be found that plaster dies are giving the greatest satisfaction. In making hip rolls or crestings on the above

presses, it is necessary of course to have blanks of suitable size prepared by auger machines.

The blank, or blanks, if two are used as is sometimes the case, are placed in the lower die, batted down by hand, and any parts needing extra clay are supplied. The lower die is then shoved into position under the upper die, the pressure made, and the die, with its contents, is pulled out on the sliding track. All excess clay and adhering parts are cut away, a plaster saddle or form fitting the inside of the tile is placed in position, the die is turned over, or dumped, on its hinges, the hip roll coming out and resting on the plaster saddle. The form now goes to the finisher, who works it over, trims off parts that are not needed, smooths up the piece, and places it on a pallet or form to dry.

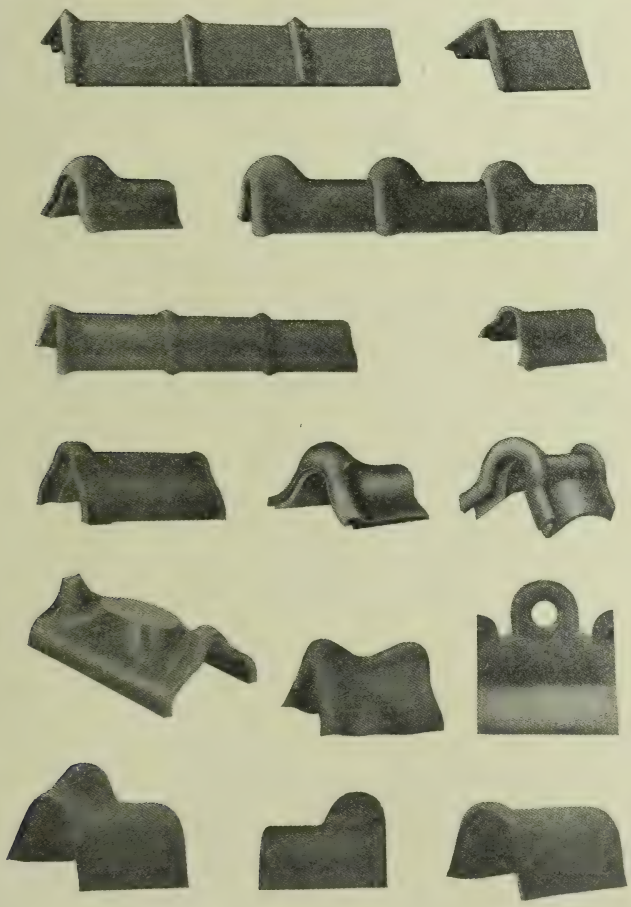

Fig. 118—Crestings.

An adjustable pitch-board upon which to dry crestings that have to be given a certain angle, as in the well known "S" cresting, is shown in Figures 121 and 122.

It will be seen that there is a base frame of two-inch by four-inch stuff. The real pitch boards are of seven-eighths-inch by twelve-inch material, the two boards being hinged together on one edge, and one of the boards being hinged to the base frame. The free edge of the other board has iron attachments to it, which engage in notches cut in the base frame, or a cast-iron notched strip attached to it. Now,

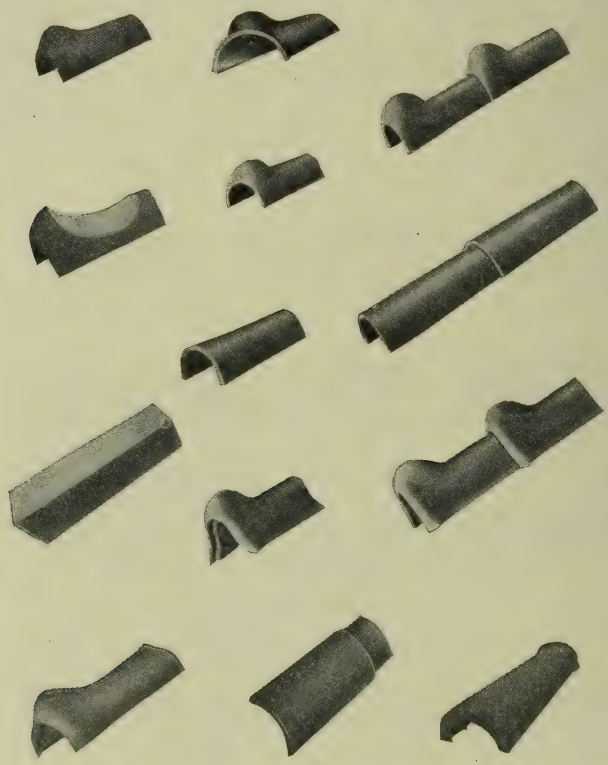

Fig. 119—Hip Rolls.

standing the boards up in an inclined position, like a letter "A," the angle can be made sharper or wider by changing the distance apart on the base plate and it only takes a moment to make the change from one angle to another. It will be noted that there are one-inch by one-inch strips nailed on the pitch boards on which the lower ends of the cresting will be supported so that it will not slide down too far and be strained out of shape. Pitch boards made in this style are convenient from the fact that when not needed they can be let down flat, and stored away in a small space.

Tapered Hip Rolls by Auger Machines.—Only one plant was found making this style of hip roll by power machinery, or, in other words, by a flow-die process. While this method is not at all new in the old world, it seems almost unknown in this country.

The Cincinnati Roofing Tile and Terra Cotta Company has for many years been making tapering hip rolls on their plunger machine by using a half-round die from which the bar issues as a semi-circular trough, having the proper thickness and with a cross-section the full size of the large end of the tile. Conical trough-shaped boxes or forms,

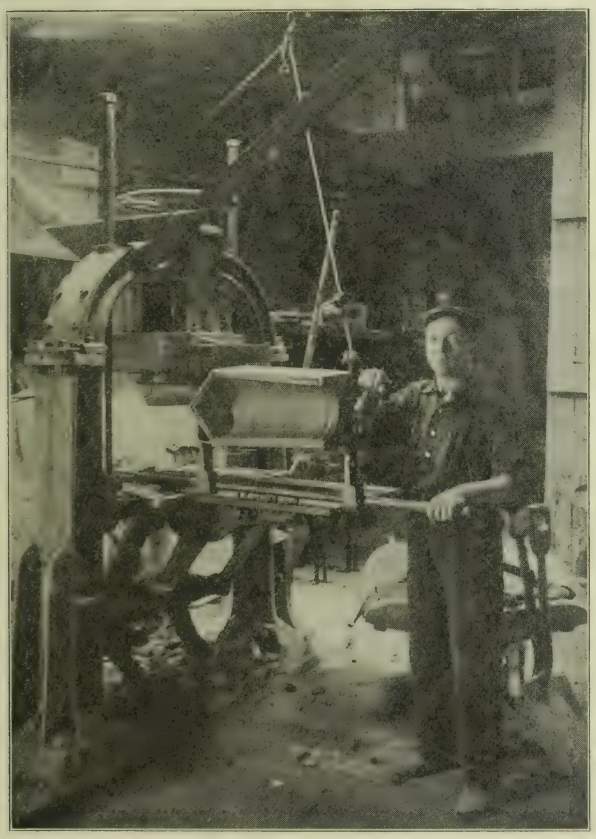

Fig. 120—Raymond Hand Press Working on Hip Rolls at Cincinnati Roofing Tile and Terra Cotta Co., Cincinnati, Ohio.

the large end of which will just admit the clay bar as it comes from the machine, are placed upon a low stand, or track, in front of the die, in such a position that they can be slid in, large end first, almost up to the die. The stream of clay being started, the operator holds one of the receiving boxes in position with one hand and guides the flow of clay with the other. The stream is compressed by the tapering mould to a cone shape. The excess clay at the small end projects up above the form. The machine is then stopped, the tile is cut off at the die, and the entire form, with the tile, is handed to the trimmer, whose duty it is to trim off the excess clay along the sides at the small end,

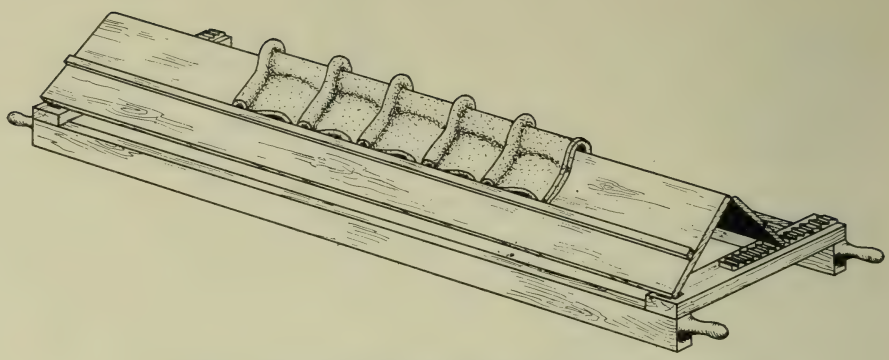

Fig. 121—Adjustable Pitch Board for Drying Crestings.

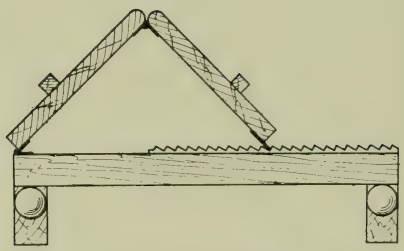

Fig. 122—Details of Pitch Board.

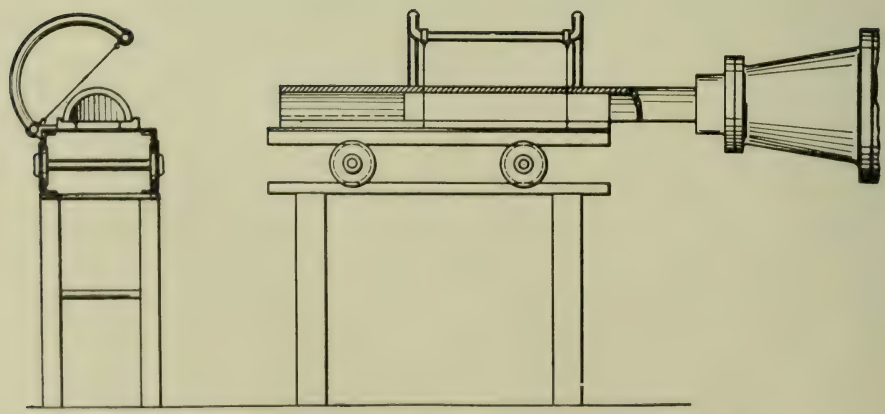

Fig. 123—Cutting Table for Handling Half-Round Tile for Hip Rolls.

cut the ends true with the form, punch the nail holes and place the piece on a pallet ready for the dryer. By having a half-dozen of the conical receiving forms, and two trimmers, it was possible to keep the machine in operation the most of the time. Three men and three boys would turn out from twelve hundred to fifteen hundred conical hip rolls per day. This method is practically only possible with a plunger machine; it would not be feasible with a continuous delivery.

With the outfit shown in Figure 123, it is believed that the output could be more than doubled by using an auger machine and the same labor force. This would make hip rolls so cheap that they could be used largely on slate roofs in the place of the metal cresting and hip covering now usually employed.

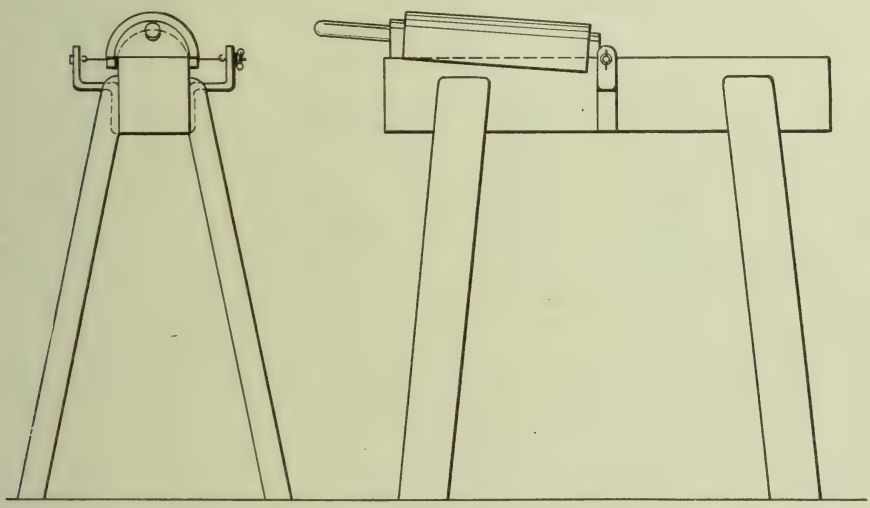

Fig. 124—Cutting Horse for Conical Hip Rolls.

The cutting frame and track may be of any design, the main feature being that the form upon which the tile travels does not extend but a short distance beyond the last cutting wire. As the tile is cut, it is pushed along by the one following. After leaving the form it is held in position by the side lugs or tracks shown in the end section. This leaves the entire tile free and clear underneath so that a paddle or form, having its outside shaped like the inside of the desired tile, can be inserted to remove it from the cutting table, and pass it on to the cutting horse for final trimming. The right angled triangles that come from the semi-cylindrical tile being made to fit down upon the conical shaped form are cut off by drawing the form and its charge over the wire on the form or horse once. Upon punching the nail holes, the hip roll is complete, ready for the dryer. By having a half dozen or more shapers or paddles, and a couple of cutting horses, the daily output could be

made to run up to two or three thousand per day without question. By using a good strong auger machine the clay could be run rather stiff to facilitate rapid handling of the tiles.

In using the ordinary drop press, or hand press, for making crestings and the larger forms of hip rolls, it will be found that the daily output of one man and a helper will run about two hundred to three hundred per day of average size, and less for the larger and more complicated patterns.

Hip Roll Starters.—The hip roll, like the regular tile, needs a "starter" or closed end tile at the lower end of the hip of the roof. More or less advantage has been taken of the opportunity to ornament the roof. An extra price is charged for fancy or ornamental hip ends, because in making them a complete regular hip roll is used, and the end is welded on extra, usually by hand in plaster molds.

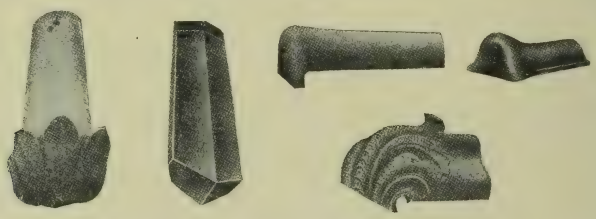

Fig. 125—Hip "Starters".

Finials.—A roof is not complete without some ornamental form of finishing piece at the junction of the ridge line with the hips, or the ridge line at the gables, or on the top of the towers.

In this class of work the roofing tile manufacturer most closely approaches to the field of the terra cotta manufacturer. Here a real chance for decoration comes into play, and the modeler can show his skill and artistic ability in the designing and making of richly ornamented pieces, ranging in size from one foot up to six or even eight feet high.

In this class of work moulds are very seldom made, because architects are so very prone to want variety. Not only will different architects not use the same ornaments, but even the same architect will hardly use his own design in a second place. Also, it is scarcely ever that two towers of the same pitch or rafter length are designed, so that the tile manufacturer has learned from experience that to make moulds of all the work turned out would be a useless tying up of money.

There are many simple finials that could be made and carried as stock finials, for the standard pitches and hip rolls, but even then, the customer is likely to want a different cresting from that used in combination with the finial, and hence it is scarcely profitable to try to carry stock. In the making of stock or ordinary finials, it will be found that each plant is equipped with a large assortment of hip saddles, or miniature roofs upon which the finials are built.

These hip saddles must be made up in many pitches to suit the varied orders that come in. It will be observed that it is made very simply, and at the same time light, for it must often be moved. This saddle is placed on a low work bench or table, with the hip end accessible. The modeler before starting sees to it that he is provided with newly pressed hip rolls and cresting of the kind desired on the completed finials; he then takes a roll of clay and builds up the hip corners with a false support for the real hip roll as shown in the following cut. He then selects two hip rolls from his supply, places them on the newly made saddles of damp clay, which have been first covered with damp paper, in the position shown in the cut. He then takes a cresting of the desired size and style, and places it in the position shown.

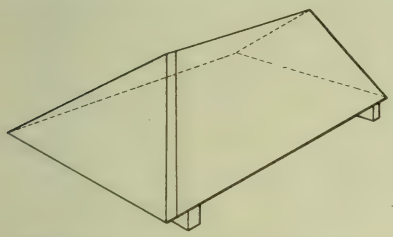

Fig. 126—A Plain Hip Saddle.

Next, he works in the "aprons" which form the connecting piece between the two hip rolls, and between the hip rolls and the cresting as shown in the cut of the completed finial (see Figure No. 128). The modeler is very careful to have the clay become firmly attached to the hip roll and cresting, so he often takes a pointed or wedge-shaped stick and works or knits the adjoining parts together.

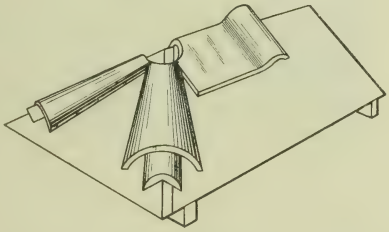

Fig. 127—First Stage of the Finial.

After the "aprons" are completed, the modeler builds up the neck for the finishing ball, which is to be added last of all. The neck is modeled onto the hip rolls and cresting in coil fashion; that is, he builds it up, a ring at a time, until of sufficient height. If a ball is to be added, it will first be hand-pressed in a two-piece plaster mould, then taken from the mould, and carefully placed on the neck previously prepared to receive it, the modeler being very careful to see that it is firmly attached.

The saddle carrying the finial is then set aside, and the work is allowed partially to dry before the smoothing and finishing takes place. Finally, it is carefully placed upon the cresting end and allowed to dry.

The number of finials that a good modeler will turn out will range from five to twelve per day, depending on the size and style.

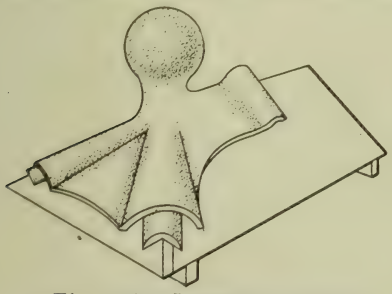

Fig. 128—Completed Finial.

Tower Finials.—In the making of round tower finials, if of the plain type, the work can be accomplished largely by a sweep revolving on a vertical axis. This was seen in use at the plant of the Celadon Terra Cotta Company, at Ottawa, Ill., a number of years ago.

A permanent table was erected about six by six feet; in the center of this table a trap door opening downward, about one foot square, was

Fig. 129—Modelers at Work at Mound City Roofing Tile Company, St. Louis, Mo.

arranged (see Figure 132). Through this trap door was a hole, through which a three-fourths inch gas pipe was run to a step in the floor and through a hole vertically above in the ceiling. This pipe represented the center axis of the finial, and served as a pivot for the sweep, or wooden shoe, which was carefully cut to the desired size and outline of the required finial.

A piece of sheet iron, forming a band around the gas pipe at the upper end of the shoe, steadied it at the top. A one-by-four-by-twelve-inch sliding strip was nailed at right angles to the main shoe to act as a guide or support at the bottom.

With the shoe in place, the modeler began to build up a central core of soft clay. This core was built out following the outline of the sweep at a distance equal to the desired thickness of the finial. This is clearly shown in the cut. After the core was complete, it was carefully covered with water-soaked newspapers. These papers were to act as a parting line between the clay of the core and the permanent exterior layer.

The work of building up the real finial began at this point, being added layer by layer, occasionally using the sweep to true up the work.

When all had been completed, the shoe was removed, the gas pipe taken out through the top, and the hole in the finial ball filled with clay. When the clay had hardened to the proper set, the trap door in the table

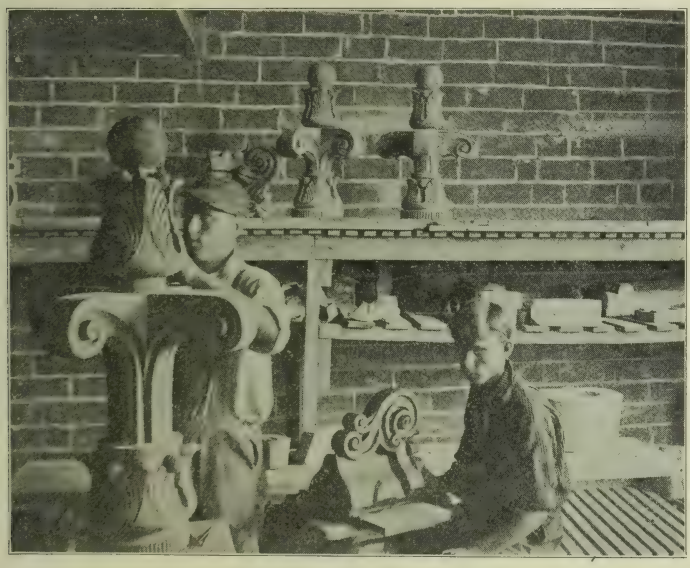

Fig. 130—Modelers at Work at National Roofing Tile Company. Lima, O.

was opened, and the core was dug out by hand, the newspapers acting as the division line. The hollow finial was then removed from the table, and, after turning over, was dried. For making large finials this outfit proved very satisfactory.

Graduated or Tower Tiles.—In the covering of pyramidal, conical or dome-shaped tower roofs, it becomes necessary to make special tiles to conform to the converging lines of the tower. These special tiles are known as graduated tiles; they are graduated in the sense that they start with full-sized tile at the eave line of the tower, and then become narrower, smaller and smaller with the diminishing circumference of each course, until they come to a common center at the top of the tower, or near enough so that the apron of the finial will cover them.

When an order calling for tower tiles is received, the foreman in charge of the special or terra cotta department carefully scales the plans of the tower, obtaining the length of the rafter and the diameter at the base. He then computes the circumference at the base in inches, and then divides the weather or exposed width of his full-sized tile into this circumference. If it comes out in an even number of courses around the tower, his next work is to go to the laying-out floor, which is usually

marked off in foot lines. If it comes out in uneven or fractional tiles, as is usually the case, he then makes use of what is known in the trade as a "closer" course—i. e., the extra space is either filled in with smaller

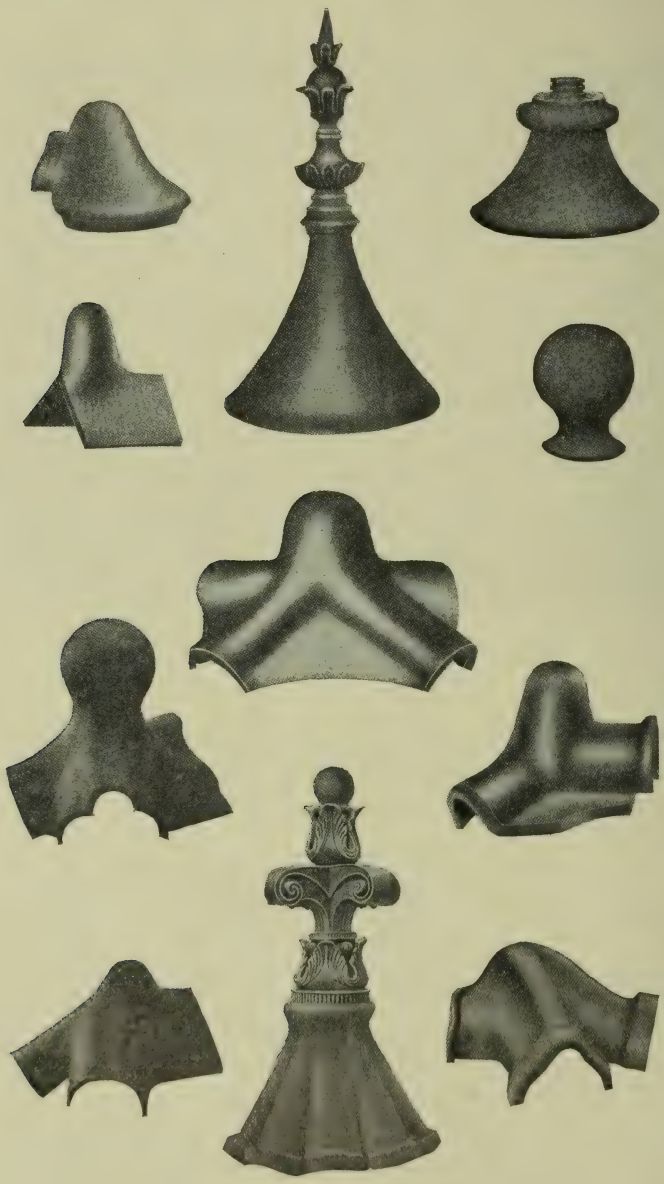

Fig. 131—Finials.

or wider tiles, as the case may require. Where smaller tiles are needed to complete the circle, it is usual to start with some other tiles in the first course than the regular full-sized tiles; i. e., one or more tiles from

the third or fourth course may be used in the first. Thus, with a little care it is possible to make the courses come out even for any tower.

Figures 135 and 136 represent a simple outfit used in laying out tower tiles, Spanish tower tiles in particular.

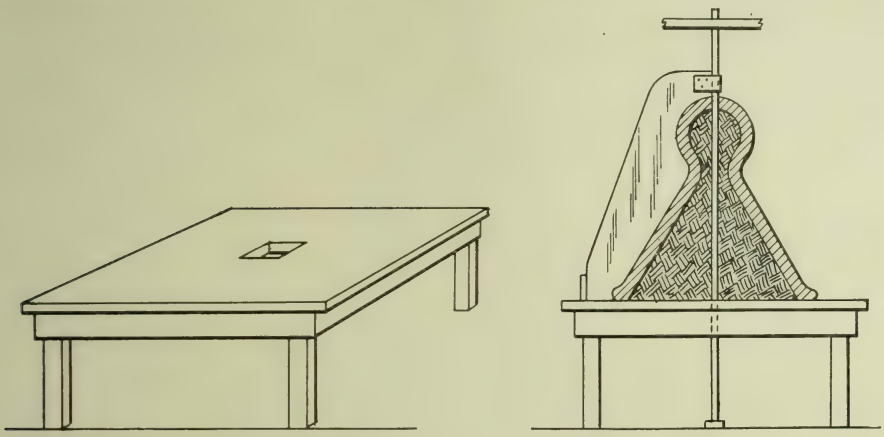

Fig. 132—Tower Finial Table.

A represents a block with two hooks attached to its top side. These hooks are spaced the exact distance apart as the width of the weather surface of a full-sized tile. The block is fastened to the floor so that the hooks are exactly even with the 0 foot line on the floor. The part B is

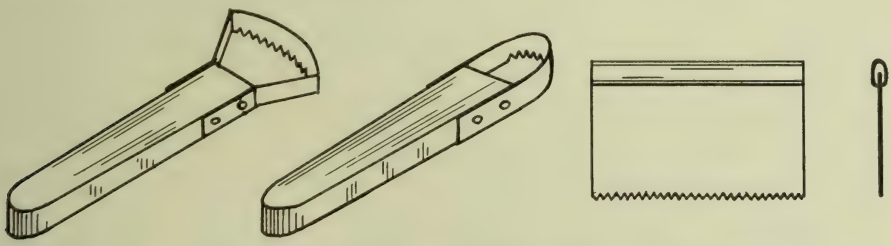

Fig. 133—Tools Commonly Used by Clay Modelers.

then fastened to the floor, on a line perpendicular to the center of a line drawn between the two hooks on Block A, and so that its hook stands at a distance equal to the length of the rafter of the tower. A line is now fastened to one hook at the base block, A, passed around the top hook and back to the second base hook, where it is fastened after drawing taut.

The rate at which the tiles diminish in width is quite different. The tiles made for a ten-foot tower cannot be used on a twenty-five foot tower, and vice versa. Hence, moulds or dies must be made for each. This is true of nearly every different sized tower. Occasionally the

tiles from fourteen-foot towers can be shifted to one of fifteen or sixteen feet. This is more easily done with Spanish tiles than with interlocking. In the interlocking tiles one has but very little play in the locks of the tiles in which the width can be swelled or diminished.

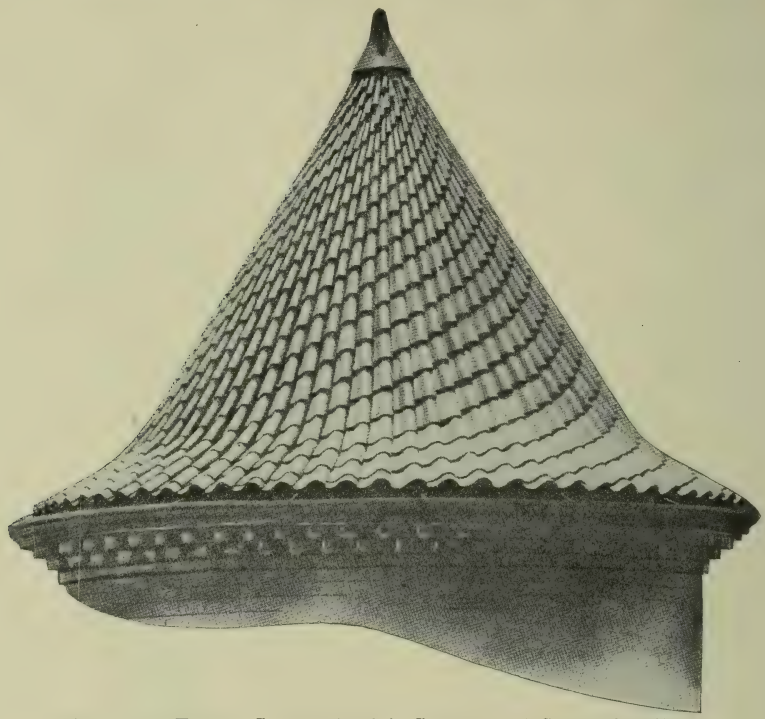

Fig. 134—Tower Covered with Graduated Spanish Tiles.

In the making of the tower tiles it will be found that the older plants are equipped with a full set of dies (plaster) for rafters of ten, twelve, fourteen feet, etc. These dies are for the most part worked on

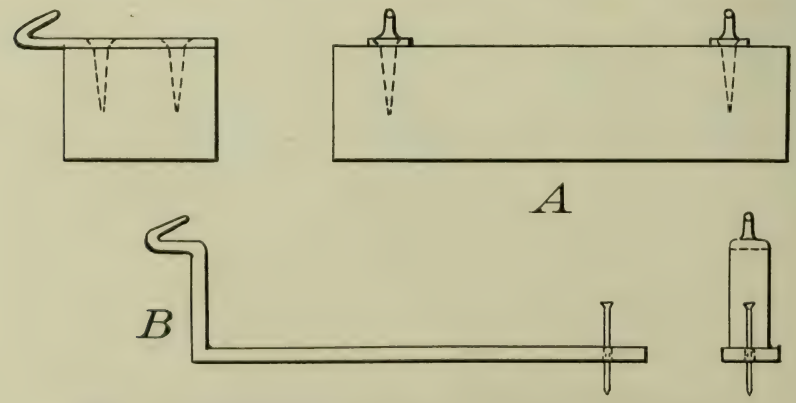

Fig. 135—Floor Hooks Used in Laying Out Tower Tiles.

hand presses. The extremely small tiles at the top are more often made by hand in plaster moulds.

On towers with twenty-five or thirty-foot rafters, where the tiles become extremely small and slender, the expedient of making double or quadruple tiles of the small ones is followed at times. Again, when two-thirds of the height of the tower has been covered, every other course will often be "jumped out;" that is, one tile takes the place of two, in order to reduce the number of slender pieces. However, this is a matter to be settled in each particular case and no law can be laid down.

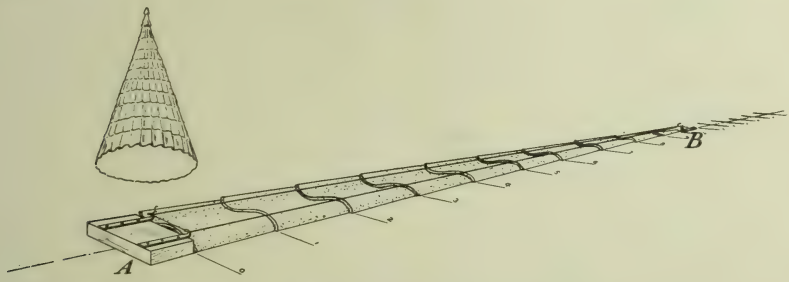

Fig. 136—Perspective View of Method of Laying Out Tower Tiles.

Rake or Gable Tiles.—It would be useless to attempt to enumerate and describe the endless variety of special tiles and shapes that the roofing tile manufacturer is called upon to produce, or sees that he must make in order to properly cover a roof.

In the regular tiles it is necessary to make rake or gable tiles in rights and lefts, to complete or close the roof at the gables of a building. In interlocking tiles, there are four different rake tiles—full right and left rake, and a half-right and half-left rake. These tiles are nothing more than the regular tiles with the side provided with a wing or lip which comes down about three inches over the facing of the gable.

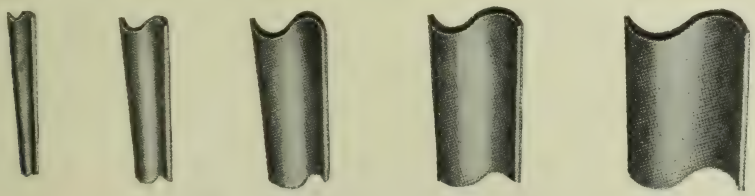

Fig. 137—Spanish Tower Tiles.

Miter Tiles.—It very frequently happens that dormer window cheeks or sides are covered with tiles, and when such is the case it becomes necessary to provide a finish at the angles or corners. This is done by mitering two tiles together as one. Thus the courses of tiles run completely around the dormer and at the same time form a covering for the corners.

Mitered Hip and Valley Tiles.—With shingle tiles it is possible to make them fit in the valleys and over hips of roofs, thus doing away

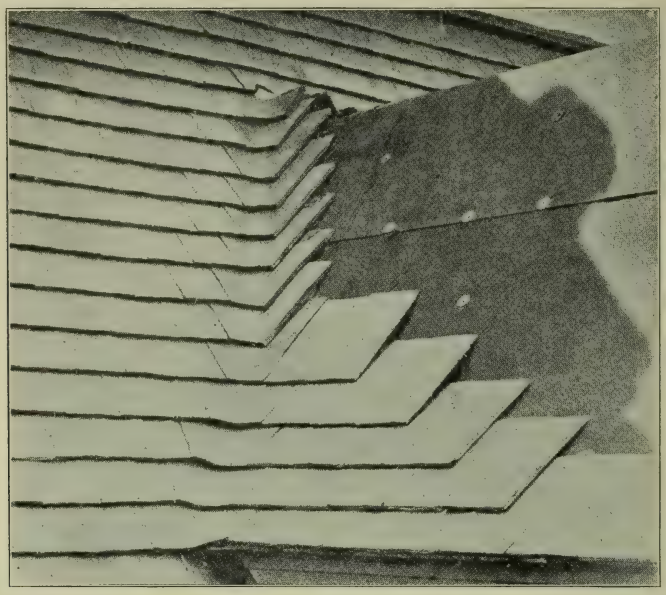

Fig. 138—Mitered Valley Tiles.

with exposed metal flashing. These mitered hip and valley tiles can be made on presses, but are most often made by hand in plaster moulds.

Ventilator Tiles.—In some instances, where there is much smoke or steam, as in foundries and workshops, it is desirable to have some means of ventilation in the roof. This situation has been met by the roofing tile manufacturers very nicely by making ventilators of the cresting tiles. The making of these ventilator tiles is hand work; that is, they are pressed by hand in plaster moulds. Very often, however, they are made by using a regular cresting, and modeling the ventilator opening and hood onto it by hand, without any mould whatever.

Deck Moulding or Coping Tiles.—In addition to the ordinary cresting, a line of deck mouldings or wall copings are commonly made. The trade in the latter is light, because wall copings are extensively furnished by sewer-pipe makers, in much heavier cross sections than the tile maker would regularly produce.

Curvilinear Tiles.—For dome-shaped roofs, or domes of towers, tiles of the regular pattern, except that they are made with a convex, outer surface, are produced. Similar curved tiles, though concave, are required for pagoda and Moorish towers. The curvature extends lengthwise of the tiles. In making these tiles, plaster moulds having the proper curvature are used. Each dome is a special problem of

itself and requires a complete set of moulds, which, as a rule, are not used for any other job.

Other Curved Tiles.—Very often in covering a curved section of roof, known as an "eyebrow," it becomes necessary to construct special tiles of extra width to allow for the increased eave line of the "eyebrow." These tiles are of the same pattern as those made on the regular machines, except that they are somewhat wider, and on the underlap side the rib is made higher to prevent the water from overflowing. These tiles are all made by hand in plaster moulds, the number required being small, and the size and curvature of the "eyebrow" to be covered hardly ever being alike.

Glass Tiles.—There is no roof so well adapted to admitting light without the use of sky-lights as the tile roof. For a number of years back, a glass tile has been made, of exactly the same pattern as the clay tile. In train sheds, shops and factories where it is desired to have overhead light, all that is necessary is to insert glass tiles, either singly or in units, along with the regular clay tiles; thus the light can be admitted at any point and in areas of any magnitude. The areas can also be changed from time to time, if necessary.

There is no other way that light can be so cheaply introduced in a roof as by the use of glass tiles, the economy being chiefly due to the fact that the first cost is the only cost. The amount of light transmitted by the corrugated surface of a tile is far greater than what could be transmitted by a plain glass pane. Another advantage is that the lines of the roof are not destroyed by unsightly sky-lights of the ordinary pattern.

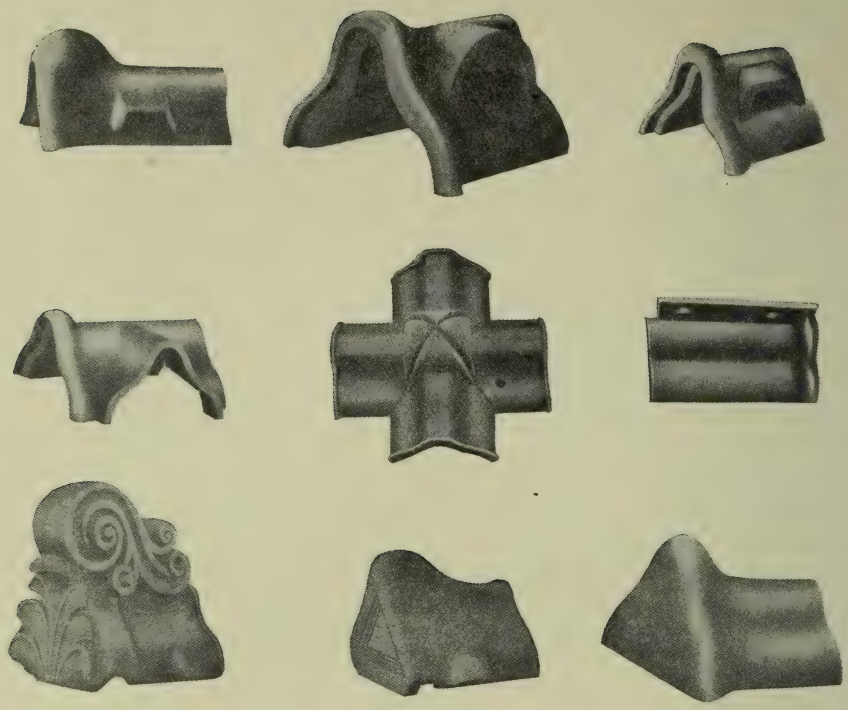

Fig. 139—Ventilator and Special Forms of Ridge Tiles.

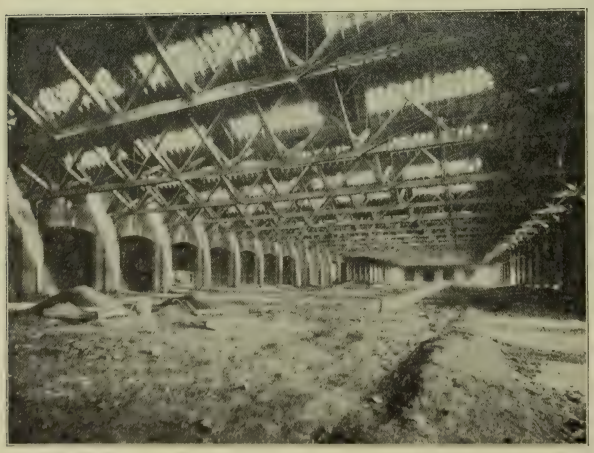

Fig. 140—Interior, Showing Glass Tiles in Use. Furnished by the Ludowici-Celadon Company.

CHAPTER VII.

THE DRYING OF ROOFING TILES.

The drying of a soft, plastic and easily deformable clay ware is the first step in converting it into a hard and durable substance. It is a process in which much skill and knowledge of physical laws may be employed, and also one in which results are constantly gotten with little or no such knowledge. From the fact that the atmosphere is the medium by which the water of the clay is carried off in vapor form, and that this atmosphere itself will supply the necessary heat to make the vaporization of the water possible, it follows that the drying out of wet clay is certain to occur, whether desired or not, unless actively guarded against. Also, this natural drying may under some conditions exceed in economy any of the artificial processes involving use of fuel, artificial movement of air, and arrangements for controlling humidity, etc.

For these reasons a great variety of practices exist in the drying of all kinds of clay wares. The selection of the best method for any given case is not always an easy task. It involves a consideration of the following factors:

(1). The nature of the clay ware to be dried. Whether its shape, size and thickness are such as favor drying safely and rapidly, or whether it is necessarily a difficult material to get through the process without defects or loss.

(2). The peculiarities of the clay itself. Whether it has good strength, moderate shrinkage, and safe drying properties, or whether it is weak, or warps badly, cracks on the least exposure, etc.

(3). The climatic conditions of the place where the drying is to be done.

(4). The fuel supply. Of what character, whether easily obtainable and cheap, or the reverse.

(5). The quality of labor available, whether intelligent and painstaking, or ignorant and careless.

(6). The value of the product and whether its price will permit expensive work being done upon it.

In general, in tropical countries where rains are frequent and excessive, and the air humid, artificial drying is general, at least to the extent of providing covered structures for protection. In tropical or subtropical arid countries, like our Southwest, and the highlands of Mexico, the most favorable conditions for outside drying that exist anywhere

are found. In such countries, the use of any fuel is very often unnecessary. But even here the ware may require conditions not naturally afforded, and dryers heated by combustion of fuel may be necessary.

In temperate zones where dry warm weather is not likely to be persistent for long periods, and where rain and frosts are certain to be frequent for one-third to one-half of the year, outside drying can only be depended upon for crude products and at favorable seasons. Nearly all high grade clay wares require artificial drying, and the best that can be done is to be able to take advantage of natural conditions when they happen to be favorable, but to be able to dry artificially when they are not.

In the northern countries, no hopes can be cherished of drying clay wares in the open, because of the little heat, and the humidity prevailing at times of high temperature. Frost prevents such work most of the time, and artificial drying equipment is necessary.

Since all of the roofing tile industry of the United States, unless a very small output among brick plants of the Southwest be considered, lies in the north temperate zone and in countries which experience sharp winter weather, and highly humid weather in the summer, the use of artificial dryers is necessary everywhere. The nature of the ware, the difficulty and expense of rapidly moving it, the perfection required in the product, and the price obtained, all require and justify the use of dryers where heat and air supply can be controlled.

The physical principles upon which drying operations rest have been carefully studied and set forth in various works.[1] For this reason no space will be used in this connection, except for such comments as come up naturally in connection with the discussion of roofing tile dryers. The object of this chapter is to show the clay workers what kind of driers are in actual use in the roofing tile industry, and in what respects they do their work well, and in what direction changes and improvements are needed.

KINDS OF ARTIFICIAL DRYERS.

There are four types of artificial dryers:

First. The Room Dryer.—This system seeks to maintain the atmospheric conditions of a warm dry summer day, in a room or building, in which the clay wares are exposed either on the floors or on racks or shelves of some sort. The heat may be supplied in any way desired, except that it must not be from the waste gases of combustion from any source, as men must work in the dryer atmosphere with safety to health and in comfort. For the same reason, the temperatures are

[1] E. Hausbrand, Drying by Means of Air and Steam. (Translated from the German.)
R. H. Minton, Trans. Am. Cer. Soc. Vol. VI, p. 269.
D. T. Farnham, Trans. Am. Cer. Soc. Vol. XII, p. 392.

limited to 100° F., or slightly above, and usually do not exceed 85° F. This system is used almost exclusively for sewer pipe, terra cotta, glass pots, gas retorts, and all large refractory wares, and to a considerable extent for pottery of all kinds, especially the large thick-walled wares, such as sanitary goods. It has even been used for bricks of various sorts, but is not well suited to wares which must be dried rapidly and very cheaply. This type of dryer has its highest example in the sewer pipe factories, and for this reason is often called the sewer-pipe type.

Second. The Hot Floor Dryer.—This system uses a fire-proof floor, usually of masonry, but sometimes of cement, or metal, the surface of which is maintained at as high a temperature as the clays will by any possibility stand. The ware is placed directly on this floor, and is dried by the heat taken up by actual contact with the floor, and from the air currents, which the floor heats and sets in motion. This system differs from the preceding in that but one method of heating is employed, viz., the hot floor, and the ware is dried on it, and not by the maintenance of a gentle diffused heat permeating the rooms or buildings. This system originated in the fire brick business, and is almost wholly confined to that industry still. Only occasional instances of its use for any other purpose are found.

Third. The Periodic Chamber Dryer.—This system includes all dryers which use a chamber of limited size, in which high temperatures can be maintained, with rigid control of the air supply, humidity, etc. The type of this sort of dryer is the potter's hot-closet, but the periodic tunnel dryers, used for bricks, are also good illustrations of this method. It varies from the first type in the high temperatures and high humidity maintained, making the dryers untenable for men, and from the general use of artificial circulation to increase the rapidity of operation.

Fourth. The Continuous Dryer.—This system includes all dryers in which the ware to be dried is fed into the structure at frequent intervals, and taken out of another part of the structure at the same intervals. It involves the idea of progressive movement of the ware through a series of automatically varying conditions of temperature and humidity, and differs from the preceding only in this continuous and progressive character. In both, the temperature and air supply must be under close control. The same structure may, in some cases, be either as a chamber dryer, or a continuous dryer, according to its mode of operation. In general, however, the difference in operation requires considerable difference in mode of distributing heat and air supplies. The type of this method of drying is the continuous tunnel brick dryers, and the method is very largely employed for bricks of all sorts. The method is now applied to some extent to sewer pipes, drain tiles, pottery, and roofing tiles. It is the most rapid and most economical of all

methods for wares of suitable shapes and sizes and for clays which will stand the treatment, but very many clays will not stand the method at all.

ROOM DRYERS.

Nearly all roofing tile works use this method in part. Nearly all of the terra cotta pieces, such as the finials, large cresting and special shapes, modeled free-hand or pressed by hand in plaster moulds, are dried at the point where they are made. These products are not put into any special dryer, but are left in the open workroom, at least until they can be safely handled, when, in some few plants, they are moved into smaller, hotter rooms, and placed upon racks or slatted drying floors, under which are placed steam pipes. These auxiliary rooms are usually about ten by ten feet, and have a single deck only, and are used only to complete the drying of the ware after it has gotten beyond the shrinkage period, and to make it ready to go to the kiln.

This system of drying is the typical one for this part of the product. In some of the later plants, where tunnel dryers are used, the terra cotta room is built over the cool end of the dryer. As the ware is made it is set along the floor (the roof of the tunnels made level) at a point where the temperature is best suited to the style or size of the piece in question. By this system it is possible to dry a considerable amount of ware without extra cost, there being sufficient radiated heat escaping from the tunnel at all times to do the drying of the shapes and terra cotta. There is a little inconvenience arising under this plan, from the fact that the clay for modeling the terra cotta must be elevated to get it to the terra cotta room on the dryer, and the finished ware must be brought down to the ground floor for loading in the kilns. The excellent drying space afforded and the waste heat here available more than offset the cost of elevating and lowering the clay and ware, which can be done very cheaply by conveyors or elevators.

Another advantageous feature of the dryer above the tunnel is that the plant can be kept more compact and better arranged. The clay comes to the end of the dryer nearest the pugging machinery, and when manufactured and dried passes down at the end nearest the kilns, where it is needed. In some plants the terra cotta work is made in a room at right angles to the main machinery room, and when the ware is dry it has to pass out around the drier and be carried its full length before reaching the kiln yard.

In the illustrations showing an outline plan of the United States Roofing Tile Company's dryer, the use made of their dryer top for a terra cotta molding and drying room can be seen. The same method was also found in use at the plant of the Western Roofing Tile Company, Coffeyville, Kansas.

PERIODIC OR CHAMBER DRYERS.

The preceding dryers have in both cases been used for the drying of the special tiles and roofing terra cotta, but not for the regular tiles which compose the bulk of the output of the plant. For the latter purposes the room dryer would be scarcely applicable, because of the slow drying which it is specially designed to give. Slow drying is necessarily correlated with small output. However, there were found two dryers for roofing tiles, which are almost as closely related to the room dryer as to the chamber dryer under which they are here classified.

The Bennett Dryer.—This dryer was employed by the Bennett Roofing Tile Company, Baltimore, Md. It was the simplest dryer found in use. It consisted of permanent shelves, or racks, in a closed room. The tiles were pressed on a small pentagon press, caught on wooden pallets, then pallets and tiles were placed on a continuous belt elevator, which took them to the second floor, where they were removed by boys or men who took them to the shelves of the drying room. The rooms were about twelve by twenty feet, divided into narrow walkways between permanent built-in racks, having slatted shelving. The racks were about four feet wide, so that tiles were put in and taken out from both sides. The heat was supplied by steam pipes laid under the racks a couple of inches above the floor. The racks being slatted, the ascending currents of heated air were able to pass among the tiles more or less freely.

This dryer was very similar to the finial or terra cotta dryers previously described. It differed in the quantity of ware crowded into a small space and in the fact that the dryer was loaded, closed, heated by piping until the contents were dry, and then emptied. The room dryer always had ware in all stages at the same time, and its conditions permitted all parts of the process to go on safely together. The Bennett dryer dried a charge at a time, and had to be cooled down for drawing and recharging, and therefore is a periodic or chamber dryer. The Bennett dryer was defective in that no particular provision was made for ventilation other than the natural leakage of any rough boarded room. The air in the dryer undoubtedly soon became fully saturated with moisture, and then drying would only take place as new and dry air leaked in to take the place of the water-laden atmosphere inside. By using ventilator stacks or a fan, it would have been possible to have gotten much more work out of this amount of dryer space. The cost of loading and unloading this dryer was much too great.

It should be understood, however, that in this particular case, the plant was not really run as a strictly business proposition. It was maintained largely as a hobby by its owner, Mr. Bennett, whose major time was taken up by the cares of a large and successful white-ware pottery.

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The Cincinnati Dryer.—The dryer used by the Cincinnati Roofing Tile and Terra Cotta Company consisted of rooms fourteen by forty feet by about eight feet high. Figure No. 141 shows a side view and cross-section of one room. Along each side, and parallel with the floor, are spiked two by four inch cleats at intervals of about eight inches. These cleats extend the full length of the room on each side, and act as the supports for the movable shelves that are put in as the filling of the dryer progresses. The shelving is pine composed of plain seven-eighths inch by ten-inch boards.

It will be noticed that though the dryer room is ceiled, it has three ventilators which extend up above the real roof of the building. At the back of the dryer, at the left-hand end, is a six-inch steam pipe or "header," out of which, at intervals of eleven inches, one-inch pipes are taken. These pass along the floor of the dryer to the other end, where they empty into a smaller header, which drains into a steam trap. The floor of the dryer is perforated with auger holes, to admit air under the pipes.

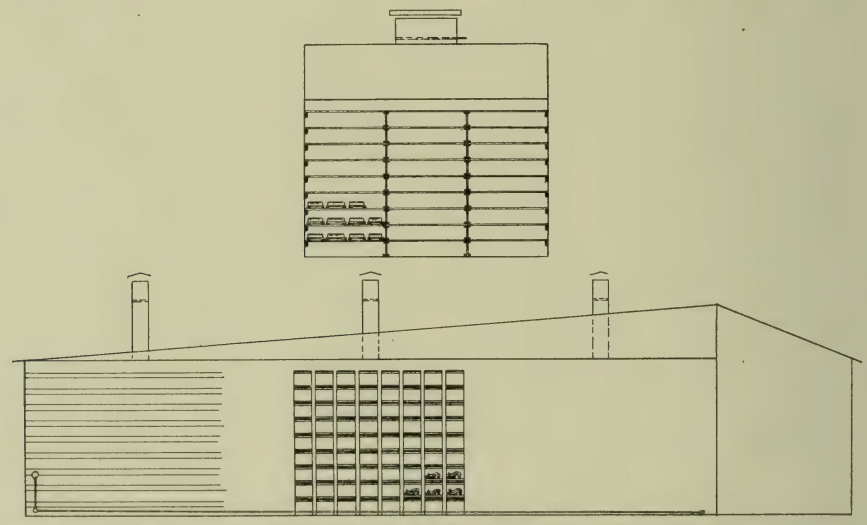

Fig. 141—Dryer Used by the Cincinnati Roofing Tile and Terra Cotta Co. Cincinnati, O.

The operation of this dryer is strictly periodic. The tiles are placed three-deep on a pallet. The pallets in turn are placed on a two-wheeled "buggy" (Figure No. 101), and run down the hallway to the room that is to be filled. A runway for the buggy extends the entire length of the dryer room. The first stand or tier of portable shelving being in place, the pallets with their tiles are unloaded upon them as shown in the end views of dryer (Figure No. 141). When the entire first stand is filled, a new one is started by putting in boards, three inches in advance of the front of the stand just filled (see side view in Figure No.

141). In order to keep the shelves from sagging down in the center, portable uprights are inserted between shelves, one above the other, as shown in the end view of the dryer. These uprights are eight inches by ten inches, with one-inch cleats nailed on both sides at each end to give it stability. Stand after stand is erected and filled until the entire length of the room is occupied. It takes from two to four days to fill a room. It is then closed by sliding doors, steam is turned into the pipes, the dampers in the ventilators are partly opened, and the drying proceeds, using live steam at night and exhaust from the engine in the daytime. The drying out of a room full of tiles takes from six to fifteen days, depending on the conditions. After the tiles are dry, they are often allowed to remain in the dryers as storage rooms until needed for setting. The rooms each hold in the neighborhood of fifteen thousand tiles. In drawing, the door is opened, a temporary bench set up, and the tiles from the outside stand are taken down, beginning at the top, pallet by pallet. Each tile is then carefully looked over, and if true and perfect is placed on a pile from six to twelve deep on a pallet, set on a buggy and trucked to the kiln.

This dryer is certainly a very crude and cumbersome affair. So far as can be seen, it has no advantages over other forms, and it certainly has disadvantages. For drying a very tender clay, its action is slow and gentle and would probably avoid much cracking, but there are better types for this purpose.

Its greatest disadvantage is in the great cost of time and labor in filling and emptying. It is necessary to put up and take down the entire shelf-and-stand equipment. If an auger machine were used to make the tiles, one man could not put up the stands fast enough to take care of the output, but the plunger machine used in this plant is of small capacity and the dryer has been evolved to work under these conditions. The construction is all cheap wood work and hence perishable by fire or rot.* The rate of drying is exceedingly slow, very frequently taking twelve to fifteen days to get tiles ready for the kiln. The heating surface of the pipes is entirely too small for the amount of work to be done, and the circulation of the air through the densely packed room is too sluggish. An exhaust fan system to increase the ventilation would be a marked improvement, either with or without increased heating capacity.

This type of dryer is not practical for any but small plants. A dryer after the Bennett plan, having fixed shelves, would prove more economical to operate in the large way, and owing to the opener arrangement would be more rapid, provided proper facilities were made to heat and ventilate the rooms.

*Since this was written, it has been destroyed by fire.—[Ed.]

The Huntington Dryer.—A periodic dryer of somewhat higher type in construction and operation was found at the Huntington Roofing Tile Company. The tiles are here placed on steel pallets, which are loaded on rack cars, which are then run into the drying room. They pass through the dryer in from twelve to twenty hours, and are then unloaded, repiled on wooden pallets, and allowed to stand in racks in an open shed until air dry. This system is quite unusual. The dryer proper was designed by the Barron Dryer Company, of Chicago, Ill. It consists of a low rectangular room, high enough to hold the rack dryer cars, and filled with parallel tracks. Steam coils are placed under the car tracks at the outlet end of the dryer, extending back three or four car-lengths, or about twenty-five feet. The heat is furnished by exhaust steam in the day time, and live steam at night. At the inlet end of the dryer is a large stack, which extends up twenty or more feet. The cars of tiles on entering pass directly under the stack, and thus come in contact with the escaping moisture-laden air from the cars farther down in the dryer. The cool green tiles often condense moisture on their surface before commencing to dry. The tiles receive the greatest amount of heat on reaching the zone over the steam coils. The dryer is provided with doors

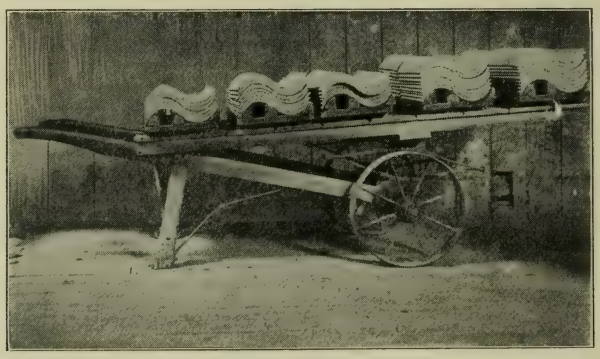

Fig. 142—Buggy of Dry Tiles on Way to the Kiln.

at each end, and the ventilating stack is controlled by a damper, so that the flow of air through the dryer can be regulated. The dryer thus far described is about the ordinary tunnel dryer with the partitions left out. But as used at Huntington, it is different from the usual operation of a tunnel dryer. The time that the tiles are in the dryer varies from ten to twenty-four hours. The tiles still show marked signs of color on the surface, from the remaining moisture, and are in the so-called "leather-hard" condition. The cars are then run out on to a transfer car, moved over to open rack sheds, and the tiles are transferred from the metal pallets which are one-eighth inch thick by about sixteen inches long. The tiles lie on these in single thickness

only, but are now stacked from twelve to twenty deep on other pallets in the shed, where they remain sometimes many days, so at least until the tiles are air dry. The sheds therefore serve not merely as dryers, but also as storage for tiles ready for the kilns. For setting, they are loaded, still on their pallets, on to trucks and taken to the kiln.

The advantages claimed by the company for this method are several: *First*, a much smaller number of cars and iron pallets are needed, which materially reduces their investment. *Secondly*, owing to the small kiln capacity, they would be obliged to run the plant frequently for short periods, whenever they had a kiln empty, but by their ample shed storage they can run the present plant continuously for a time, until everything is full, and then shut down for a considerable time, until the sheds are nearly depleted. They consider this more economical than the other plan.

There are, however, some stronger reasons why this method is locally a success. As stated elsewhere, this company has been running exclusively on flat shingles, and without doubt is turning out a greater per cent. of number-one goods than any other concern on this style of tiles.

In studying the conditions under which they work, we must turn back to their raw material. They work two shales, one a fat plastic body which lends strength and good color; the other is a very sandy shale, which is used to control the shrinkage. The blending of these two shales is carefully watched. The grinding and screening is to one-sixteenth inch mesh. The clay is pugged rather softer than usual, as they have only small machines for making the shingles and cannot work the clay very stiff without breakdowns. The tiles come from the auger so soft that the pallets must be perfectly straight, or the tiles will be warped by the pallet. This soft condition of the clay permits the grains of hard shale to find water so that they slake or soften before the drying takes place. This permits the internal strains to adjust themselves. The drying proceeds slowly; only enough of the water is evaporated in the dryer proper to bring the tiles to a condition where they can be handled without marking. Thus very few if any drying strains have been developed in the tiles, and if there are any such, upon being placed in the open sheds, the extremely slow drying in piles allows them to readjust themselves. So that, when the tiles go to the kiln, they are in the best possible condition.

This method of drying as a whole, while producing very good results in this plant, can not be recommended for general application. The cost of the extra handling is considerable, and we have no evidence that the clay mixture would not produce equally good straight tiles in as high proportion by rapid drying in an efficient dryer as by this plan. We can only say that good results are secured by the present cumbersome and expensive process, made necessary by the lack of correlation of the

making and burning departments. Another bad feature of the system is that it can only be operated during the warm months. This, however, could be easily improved or overcome by having the sides closed by doors or canvas curtains, and with a few lines of steam pipe, or a little waste heat from the kilns, the sheds could be kept at a temperature well above freezing during the winter months. There are some objections also to the dryer itself. The steam pipes under the floor are extremely hard to get at in order to make repairs. The draft or the circulation of air through the dryer is created entirely by the stack. Under favorable atmospheric conditions, the ventilation will be sufficient, but on warm damp days the draft will become very sluggish, and the drying in consequence will almost, if not entirely, cease.

Another bad feature is that the interior space is one large open room, in which the natural flow of the hot air will be along the lines of least resistance. This most frequently is along the ceiling, and at times it crosses the dryer at various angles to the point in the vent stack having the best draft. If the space were divided into single or double track tunnels, the air currents would be much more under control.

The Cloverport Dryer.—A similar dryer is in use at the Murray Roofing Tile Company. The tiles at this plant are made in the same manner as at Huntington. They are loaded on iron rack cars, and run into an eight track single room dryer about seventy feet long. The heat for this dryer is supplied from two sources: first, steam pipes placed on the floor, and second, a fan and steam-coil system, furnished by the Green Fuel Economizer Company, Matteawan, N. Y. The use of the fan tends to produce a better circulation, but the dryer is largely open to the same objections as the Huntington dryer. There is no direct control of the movement of air through the room. The use of both steam pipes on the floor and a hot air fan system is unusual, and at first sight, might seem unnecessary. But the presence of the hot pipes all over the floor insures circulation by convection currents, and while the fan may be sending volumes of warm air into the dryer, it may be following lines of least resistance around or across the tops of the cars, and thus without the aid of the pipes a poor result might be attained. The open room is chiefly responsible for this, and if the space were cut up into tunnels, the double heating system would be less likely to be of use.

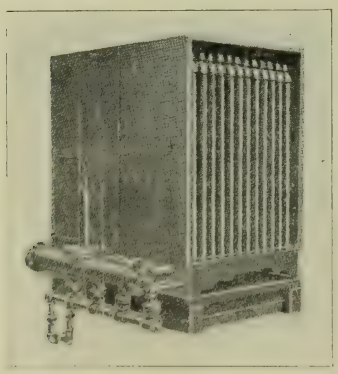

Fig. 143—Steam Coils.

One thing may be said of the large open room, viz., the mass of ware contained at once is great, and the proportion of walls and dead work to heat up and cool down with each charge is much reduced. The

ware is slower to dry in such a mass and is safer from cracking on that account. It is a method which might be considered with a tender clay, where it would be rejected for a strong, safe drying clay.

CONTINUOUS DRYERS.

Tunnels Heated by Steam.—This style of dryer is used in five of the roofing tile plants, a larger proportion than any other type. It is possible that this large use is not due to any special superiority over other styles, but to the fact that it can be very easily adapted to plants of various sizes, and with less initial expense than the waste heat system. Continuous dryers are usually built in the form of single track tunnels, from eighty to one hundred and twenty feet long, and from three feet six inches to four feet six inches in width, to suit the cars. The matter of single or double tracks is not of much importance as far as the drying is concerned. There is less wall to keep hot in the double track tunnels. The real advantage of the double track tunnel is that it is easier cleaned and more accessible in case of a breakdown, or some other trouble with any of the cars. In cost of construction, it is a little cheaper to build the roofs of single tunnels than with double, when either brick arches or reinforced concrete is used as the cover. If brick arches are used, the rise of the arch gives a waste space above the tops of the cars, and the hot air, unless prevented by stoppings fitted in at intervals, will tend to pass along over the top without coming into much contact with the ware. Flat roof construction, either of book tiles, or blocks, or cement concrete, are all perfectly feasible, and free from the above disadvantage.

The length of the tunnels should depend on the particular clay to be dried; shorter for the easy quick drying clays, and longer for those more plastic and difficult to dry. It is very rarely that the dryer need be over one hundred and ten feet long, exclusive of the loading and unloading tracks at either end. These tracks as usually built are of two car lengths at the receiving end, and three or four at the unloading or cooling end.

The outside walls are usually nine or thirteen inches thick and the inside or partition walls are four inches for single track and nine inches for the double track tunnels. The arch of the roof, if of brick, is usually from four to eight inches thick, and is coated with cement if to be exposed to the weather. If used as the floor of the terra cotta drying room, it is either made level with sand or cinders and then cemented, or a slatted board floor is laid over it.

The heat necessary for these dryers is supplied by either live or exhaust steam, or both at the same time. The heating system consists of a series of independent steam coil units arranged along a header in a compact group. These coils are contained in a metal hood or case,

and the air is blown or sucked through the coils, coming into intimate contact with them. These heating coils are so close spaced, and the frictional resistance they offer to the passage of air is so great, that they

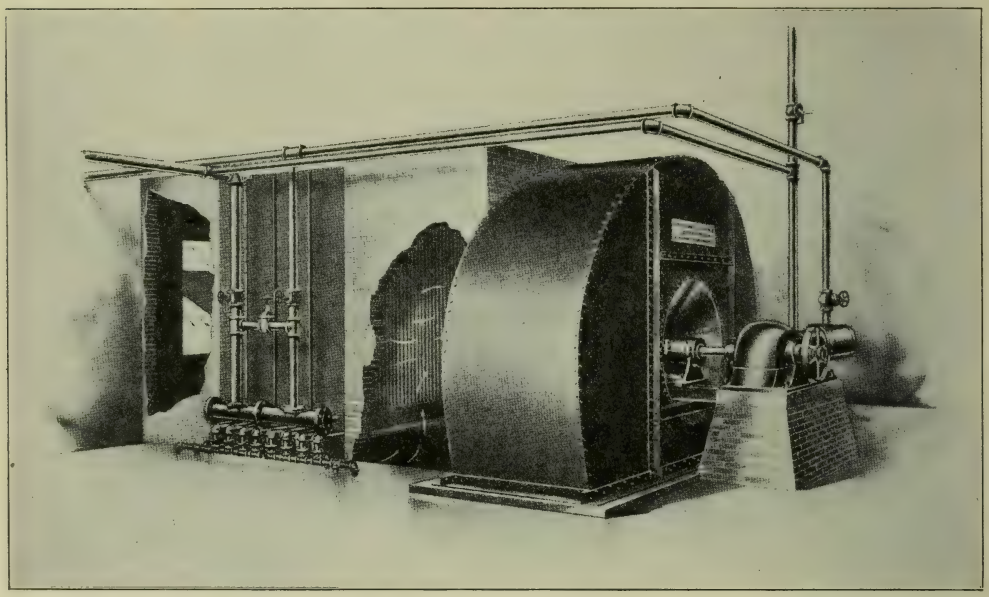

Fig. 144—Fan for Dryer.

cannot be operated without power draft in some form. Fans are generally used to pull the air in among and through the coils. The air takes up heat rapidly as it passes through, and is often too hot and is diluted with cold air at the fan so that a mixed and tempered air current of greater volume is obtained. The air is delivered to the tunnels through underground flues usually, which connect into the lower end of the dryer near the door.

In some dryers of this type the hot air is all liberated at a single opening in each tunnel; in others it is liberated through smaller holes, at intervals of each two feet or so, back to a distance of twenty to thirty feet from the outlet end. The distance that these hot air vents in the floor can be carried back up the tunnel will depend very largely upon the drying quality of the clay. The safer the clay, the farther toward the incoming end can the hot air be carried. Tender clays do best when only one opening is made at the lower end.

The fact that the steam coils are in independent sections admits of easy adjustment as to the quality of heat furnished. The source is also under control, as either exhaust steam or steam direct from the boiler, or both, can be used at the same time by admitting them into separate sections of coils. This feature, in connection with regulation of the speed

of the fan, gives the operator almost perfect control of the drying conditions. It is common at the upper end of the dryer, where the moisture-laden air is discharged, to have a small auxiliary fan to assist in moving the wet air out of the dryer. In some cases ventilators are used, but these are not so satisfactory as the small fans. There seems to be no first choice as to the selection of fans. The following firms have each installed one system in a roofing tile plant: The American Blower Company, Detroit, Mich.; The New York Blower Company, Bucyrus, Ohio; The Green Fuel Economizer Company, Matteawan, N. Y.; The Buffalo Forge Company, Buffalo, N. Y.; The Garden City Fan Company and The Sturtevant Company, Boston, Mass.

The Parkersburg Dryer.—The equipment for this dryer was furnished by the New York Blower Company. The above sketch was taken largely from their drawings. The terra cotta room above the tunnels was added by the owners.

It will be seen that this dryer is of the single track type, the tunnels being forty-four inches wide, six feet high and eighty feet long. The large exhaust flue at the upper end is fifty-four inches by fifty-four inches, and is provided with a low stack at one end for ventilation. In most cases it would be better to have an exhaust fan at the stack end, but in this particular case the tunnels are comparatively short, and the fan is only lightly loaded, so no trouble is experienced from sluggishness on the part of the dryer.

The hot air ducts under the floor of each tunnel are eighteen inches by twenty-four inches at the intake, and taper up to about six inches by eighteen inches at the inner end, which is about twenty-five feet from the main flue. The latter, leading from the fan to the dryer, is forty-one inches by forty-one and one-half inches, the bottom rising gradually until it is only about twenty-four inches deep at the tunnel furthest from the fan.

The fan is a regular ten-foot three-quarter housing, bottom discharge steel fan, the wheel of which is six feet in diameter by three and one-half feet face. The power necessary to operate the fan is furnished by a small twelve horse power horizontal slide-valve engine, made by the company that made the fan.

The heater for this outfit consists of eight independent sections of steam coil. During the daytime exhaust steam from the engine operating the plant is used, being brought to the dryer through a five-inch asbestos-covered line. The exhaust from the small fan engine is also turned into the heater, so that very little loss of steam takes place. At night the heater is supplied by a three and one-half inch live steam line direct from the boiler. The usual time of drying in this dryer is twelve hours, although ten hours have been found sufficient.

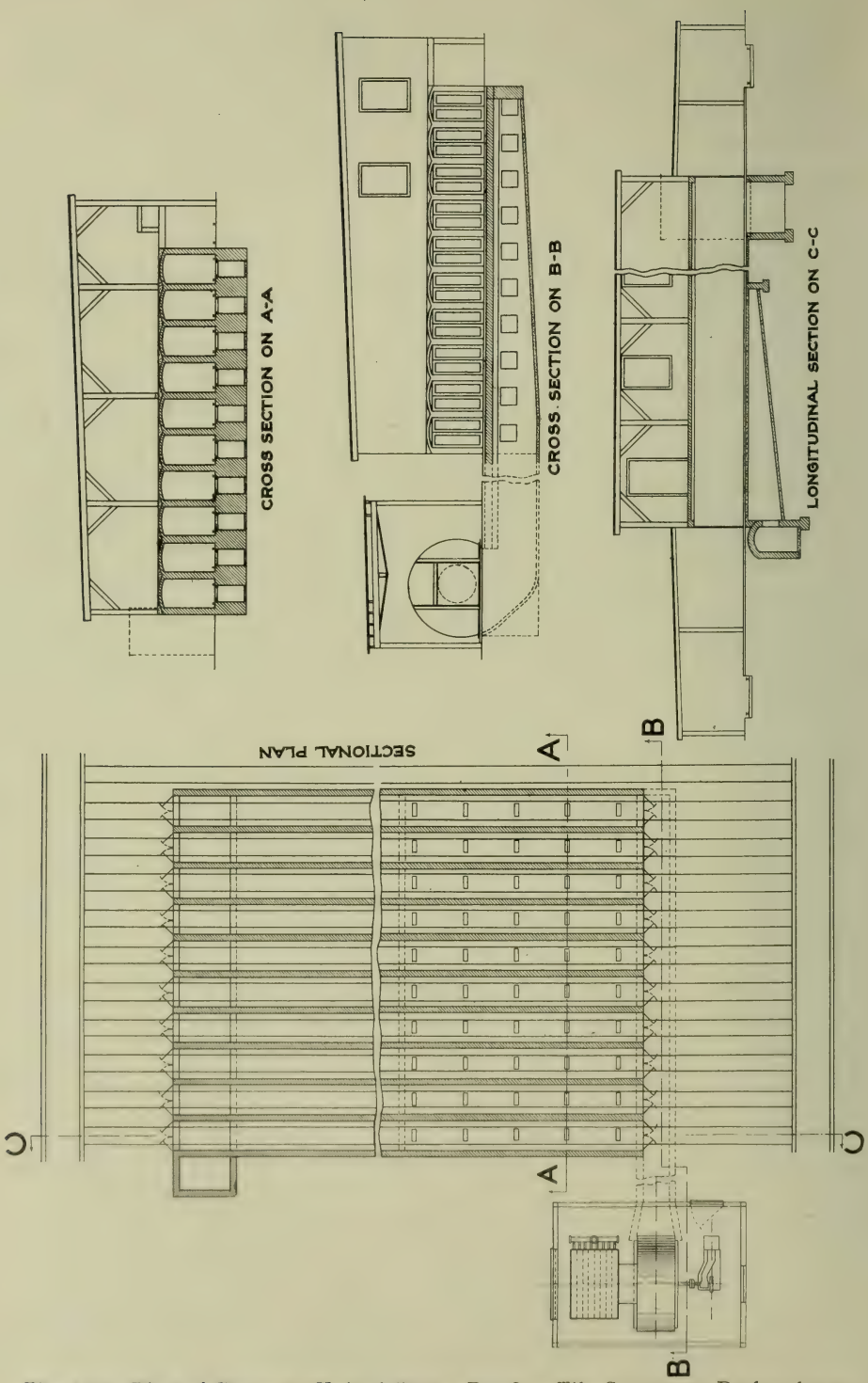

Fig. 145—Plan of Dryer at United States Roofing Tile Company, Parkersburg, W. Va.

While there are roofing tile plants with dryers of much larger size than the above, they are the same in principle. About the only objection to this type of dryer is that during about one-half of the time it is necessary to furnish live steam to the coils. The engine of the plant is not in operation more than ten hours, so that a boiler must be kept in commission for no other purpose than to furnish steam to the coils and fan engine.

There are many points in favor of this type of dryer:

First. It is suited to roofing tile plants of moderate size, where there are not sufficient kilns being burned to give a steady supply of waste heat.

Second. Its supply of heat is under perfect control—by opening or closing steam valves it can be increased or decreased at will.

Third. The rapidity of the process is favorable to the avoidance of scum.

Fourth. The economy of the dryer, if worked to its capacity, is very great. If worked to only a half or a quarter of its capacity, however, the loss of heat by unsaturated gases escaping is very high.

Fifth. The dryer is substantially independent of outside weather conditions, either for temperature or draft.

Sixth. The system is elastic—by building more tunnels, adding a few more coils of heating pipe and speeding up the fan, a considerable increase in output can be secured at small cost if the original installation was at all generously designed.

After the dryer is once filled, and the work is properly started, it will be found that the cars entering the dryer pass at once into a warm, moist atmosphere, where the tiles warm up without starting to dry. After a car or two has been pulled out at the lower end, and the car of green tiles is moved down into the dryer a couple of lengths, the drying commences, and from time to time as it moves forward, it encounters constantly hotter, dryer air, until it passes out at the lower end, with the tiles perfectly dry and hot, ready for the kiln.

The tunnel dryer using steam is and will be the one most largely used in roofing tile plants. It cannot be claimed as the best in economy of fuel, but its convenience and freedom from dependence on the kilns for heat make it more popular. The fuel cost of drying is not a serious item in the roofing tile business anyway, and convenience is very apt to outrank it, with most manufacturers.

Tunnels Heated by Furnaces.—This form of dryer, originally brought out as a patent by Sharer, and at one time extensively used, has given place largely in later years to others which derive their heat, in part at least, from the waste heat of engine rooms or kilns. Only one plant, that of the National Roofing Tile Company, Lima, Ohio, was found using a furnace-heated dryer. This dryer contains thirty single track tunnels, sixty-seven feet long, and about three feet wide

and six feet high, each. The method of applying the heat differs from the usual Sharer dryer type, in that the flues under the floor are at right angles to the tunnels, instead of coinciding with their lengthwise axis, as usual. The furnaces are built on both sides of the dryer, alternating with each other; i. e., the furnaces on the right-hand side deliver into flues, which pass under the floor to chimneys at the left-hand side, and *vice versa*. Thus a furnace and a chimney alternate along both side-walls. The idea of having the furnaces alternate in direction was to equalize the temperature from side to side of the dryer.

The furnaces are of the common flat-grate type; the dimensions of each are about eighteen by thirty-six inches. When this dryer was first installed, it was gas-fired, but as gas became more expensive, resort was had to coal. The air for ventilation is let in on the floor level at the outlet end. The escape is through numerous vent pipes or stacks in the roof.

In firing the dryer under normal conditions, the furnaces nearest the outlet end are fired much harder, or at shorter intervals, than those at the inlet end, in order to adjust the temperature to the continuous dryer principle, and not have the green tile entering at once with an extremely hot, dry atmosphere. The use of small individual stacks all over the roof instead of the single delivery at the inlet end is contrary to the continuous principle, and resembles the typical periodic dryers for bricks. The dryer is therefore not true to either type, but in operation most nearly resembles the continuous type.

The advantages of this method of heating a dryer are few, if any, for the roofing tile industry, while the disadvantages are very apparent. In the first place, the cost of operation is very high. The consumption of fuel takes place under very wasteful conditions, and at the same time requires the attention of one man, day and night. The proportion of the heat generated which finds its way up through the fire-brick floor and performs any useful work in passing vertically upwards from the floor to the roof and out, is very small indeed—probably not ten per cent. The largest part of the heat passes out of the stacks at the ends of the flues, without ever entering the dryer at all, and what does enter the dryer is not brought into contact with the ware for a long enough time.

The control of the temperature is not at all close. The tunnels along the sides and over the furnaces receive much more heat than the central ones. There is no means of regulating this difference.

The provision for admitting and controlling the air in this dryer is also poor. The low vent-stacks furnish but a slow circulation, and as the air is admitted on the floor, and not under it, and all at one end, the opposite end is nearly devoid of draft, which causes the deposition of dew on the tiles, and tends to bring out whitewash from the soluble salts in the clay.

There is still another feature not to be overlooked, viz., the flues are very apt to become choked or clogged up with soot, when the firing is done with coal. Even though they may not become so choked as to stop operations, they will become coated with layers of soot, which is an excellent non-conductor. Radiation through this soot layer is very slow, and the greater part of the heat passes up the chimney into the air.

In any case, it certainly is poor economy to consume fuel for drying purposes when there is daily much more heat wasted around the kilns and exhaust steam from the engine than would be needed to do all such work.

Tunnels, Using Waste Heat from Kilns.—It is the usual plan in this country, after a kiln of clay wares has been burned off, to allow heat contained in the ware and kiln itself to escape or radiate into the air, without any attempt being made to utilize it. Hence the term "waste heat" has been applied to heat obtained from this source.

While the use of waste heat for drying is the most economical in the sense that no new fuel is consumed to dry the ware, and should be everywhere used if possible, it is only recently used in America in any important way, and up to the present the roofing tile makers have been slow to adopt it. The limited use of this method can be explained. Many of the roofing tile plants are only of moderate size, having from two to four kilns; hence the supply of waste heat is not continuous, and other provision would have to be made to furnish heat, when there were no cooling kilns available. This is accomplished in some of the plants that are using waste heat, by having steam coils in connection with the waste heat system. At most clay plants, an auxiliary furnace, often of large size and considerable cost, is used to supply heat in connection with the fan system, when no hot kilns are available. The auxiliary furnaces, if constructed to heat the air indirectly, by radiation, are satisfactory as to quality of hot air produced, but are costly. If constructed so as to utilize the waste products of combustion, or direct heat, they are economical in fuel consumption, but scum the ware by sulphur fumes if there is the least chance. Hence, for wares which are sold on their looks, the direct heater is justly feared. The necessity of constantly having to shift from waste heat to other heat and back again has no doubt held back the use of this system as much as any other one condition.

The first cost is considerably over that of the steam system, and this has probably held some plants back in adopting the waste heat system. However, this reason should not stand in the way, for in the end any other system will exceed the waste heat system in cost of operation and maintenance.

The equipment for a waste-heat dryer, as usually constructed, consists of either single or double track tunnels built on the same plans as

for steam drying. The underground flues in the tunnels and those from the dryer to the fan remain the same. The fan and engine will differ very little. They may be furnished a little larger, and it is advisable to have the main shaft bearing of the fan water-cooled. A trunk flue, or tunnel, leading from the fan house to the kiln yard, with side branches reaching out to each kiln, must be constructed. This system of flues can either be underground or overhead, the former being the general practice. Only one plant was found using the overhead system. By referring to the illustration of the Western Roofing Tile Company (Figure 183), the large overhead flues, or ducts, can be seen leading from the kilns to the fan house. The heated air may be taken from underneath the kiln by a cross-flue. This method is the best, because the air coming in at the top of the kiln or over the bags has to pass down through all of the ware before reaching the flue, thus accomplishing the most work. However, one drawback to this method has been experienced, viz., to find a damper that will hold tight, so that when the kiln is burning the gases of combustion will not be sucked through into the waste heat flues by the fan. These gases of combustion are quite likely to form whitewash or scum on the green tiles in the dryer. Also danger arises from their escaping into the factory workroom, thus making the air unhealthful for the men.

There is no serious mechanical difficulty about making air-tight hot-air valves to stand temperatures exceeding 800 degrees centigrade. but it cannot be done with simple iron castings, for they will warp, crack, oxidize and get leaky. The best method is to use well-made, true fire-clay slabs, covering a hole in the flue bottom. If iron is used it is best to depend on a hemispherical bell to cover the opening in the flue, and let this bell seat itself in an annular cast-iron ring filled with fine sand. If, when the valve is open, the bell is pulled up out of the path of the gases, it will not warp or crack, and can be used for a long time. The sand joint is tight enough for such work as is here under discussion.

Another method of drawing the heat out from a cooling kiln is through the wicket (door) by a portable gooseneck. Instead of having the waste heat flue lead back under the kiln bottom, it is carried to a point in front of the wicket, where it ends as a well hole, which is carried up to the yard level. A cast-iron manhole with a tight lid, such as is used for cistern tops, is used to cover the well hole. When a kiln has been burned off, and is ready to draw upon, a hole is worked through the lower part of the wicket, the lid to the manhole is removed, and the coupling is made between the two with the gooseneck. The latter is merely a heavy sheet-iron elbow, fifteen to twenty-four inches in diameter, with handles for lifting while hot. The joint between the gooseneck and flue is made tight with mud. After all available heat has been taken from the kiln, the gooseneck is removed, the lid put back in the manhole, and the kiln is entirely isolated from the drying system.

There is no possible chance for back draft into the waste-heat flues. The hole in the wicket for insertion of the gooseneck can best be provided for by having a large drain tile or sewer pipe built in upon setting up the wicket. This is then stopped with bricks and mud daubing. On removal of these the balance of the wicket remains in a good, tight condition.

With rectangular kilns, or round kilns having two doors, it is common to keep the fire holes and crown hole closed, and admit the cold air through the door or wicket in the opposite end or side of the kiln, so that the air has to pass through all of the ware on its way through. This is a doubtful expedient, however, especially in the beginning, when the kiln is at its highest temperature. The admission of cold air through the wicket is very likely to chill and crack some ware. It is safer to take the air in, for a time at least, through the fire holes or crown. At the fan it will be found necessary to have a cold air inlet, whereby the hot air from the cooling kilns can be diluted to suit the needs of the dryer.

The Groveport Dryer.—Where the heat is not sufficient from the cooling kilns, a system can be installed whereby a considerable portion of the heat can also be extracted from the combustion gases of the burning kilns as well, without allowing the combustion gases themselves to enter the dryer. The idea is not new, but is very little used in the ceramic industry, and not at all in the roofing tile plants. A plant was installed in 1906 at the plant of the Columbus Clay Product Co., Groveport, Ohio, by W. G. Worcester, in collaboration with W. D. Richardson, of Columbus, Ohio.

The system required two fans, one to create the draft for the kilns and to deliver the hot combustion gases to the heater, and the other to pull the waste heat from the cooling kilns or the heater, or both, and deliver it to the dryer. The system as installed at Groveport provided a double set of flues from the fan house to the kilns. One flue handled the waste heat of cooling only, and its neighbor the gases of combustion. The waste heat was taken from the wicket of the cooling kiln by a gooseneck, and after passing through the flue entered the dryer fan, which delivered it direct into the tunnels of the dryer.

The gases of combustion, upon reaching the kiln bottom, as they would under natural draft, passed into the smoke flue, which was directly underneath the waste-heat flue, being separated from it only by a four-inch fire-brick arch. Some of the heat of the combustion gases was thus radiated through this arch all the time into the hot-air flue overhead, but the bulk of it passed on to the heater.

This was a brick structure, resembling roughly a tubular boiler on a large scale. The hot combustion gases were delivered by the fan into the lower part of one end of the heater, and passed through six-inch iron horizontal gas pipes to the opposite end. They then were turned

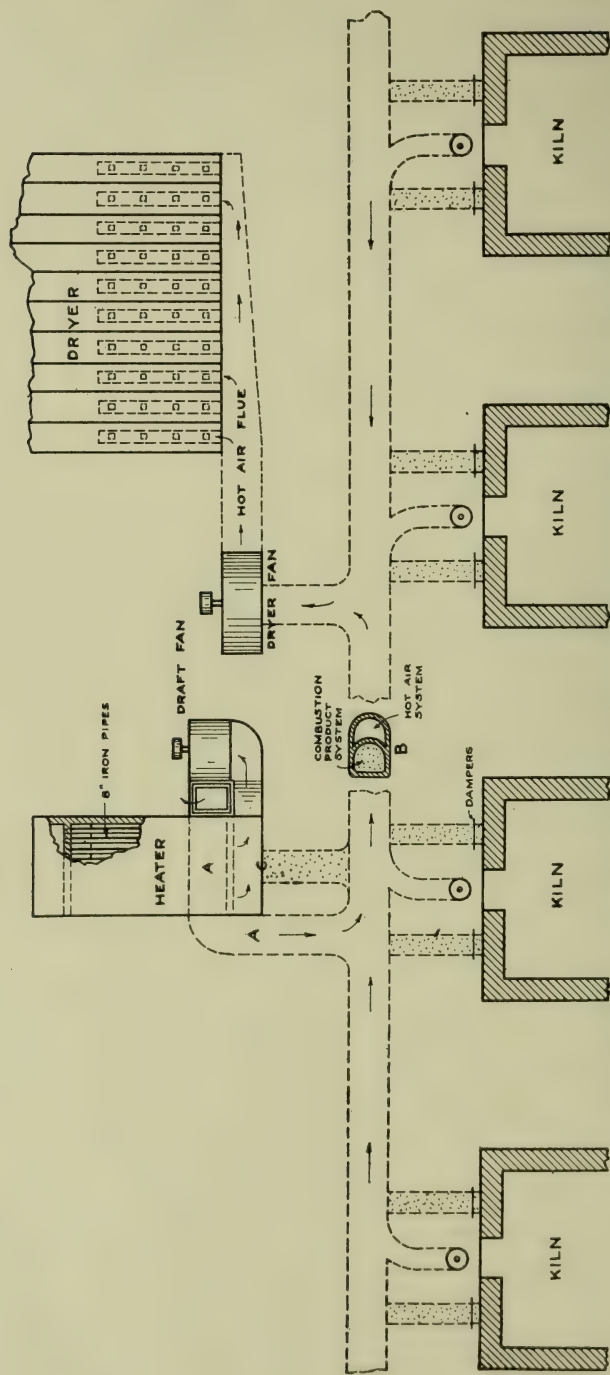

Fig. 146—Ground Plan of Groveport System of Heating Air for Drying Purposes.

back through the upper half of the structure, through more six-inch piping, from whence they went to the fan, which was of the vertical discharge type, with a six-foot wheel. The space surrounding the six-inch iron pipes was also divided into two sections and connected to the dryer fan. Cold air was admitted into the space surrounding the iron pipes at the end where the combustion gases escape, and then passed through the apparatus in reverse direction to that of the combustion gases. It passed out of the heater near where the hot combustion gases entered it, thus coming in contact with hotter pipes the further it traveled in the pipe system . The total travel in the heater for both air and combustion gases was about thirty-five feet, which was found sufficient to take the hottest gases from a burning kiln and cool them to a point where one could easily hold the hand in them at the discharge of the fan. This shows that the heat had been largely extracted from them, but it does not prove that much was actually effective in the dryer.

In Figures 146 and 147 the waste-heat flue system has been left unshaded, and the lower or combustion product flue system has been shaded to enable the plan to be more easily understood. The success of the system is by no means bound up in this particular construction. The flues could have been built separately with equal ease, but it was thought that the placing of the hot combustion gases in the lower set of flues would not only be cheaper in construction, but would assist in preventing the loss of heat from the hot-air flues overhead. The fans were located close together with a view to driving both from the same shaft.

While this system as constructed at Groveport was proved economical as a whole, it developed several objectionable features. First, the metal pipes through which the combustion products were drawn were constantly contracting and expanding with temperature changes, and were pulling loose at their point of passage through the brick partition walls. Even with plastering the joints, using magnesia, asbestos and similar materials, the constant change of size and length was too much, and mixture of the two gas streams ensued. Second, the iron pipes were subject to constant attack from sulphuric acid in the combustion gases. Third, replacement of the metal parts would make the cost high and the shut down of the plant necessary while repairs were in process of installation.

Regenerative Hot Blast Stove Dryer.—The above faults could be largely or wholly overcome by the substitution of a regenerative fire-brick hot stove, such as is used by the iron blast furnaces. This plan would call for the use of two stoves, or possibly more, one of which would be in service heating the air that would be flowing through it, while the other would be taking up heat by the passage of the kiln gases through

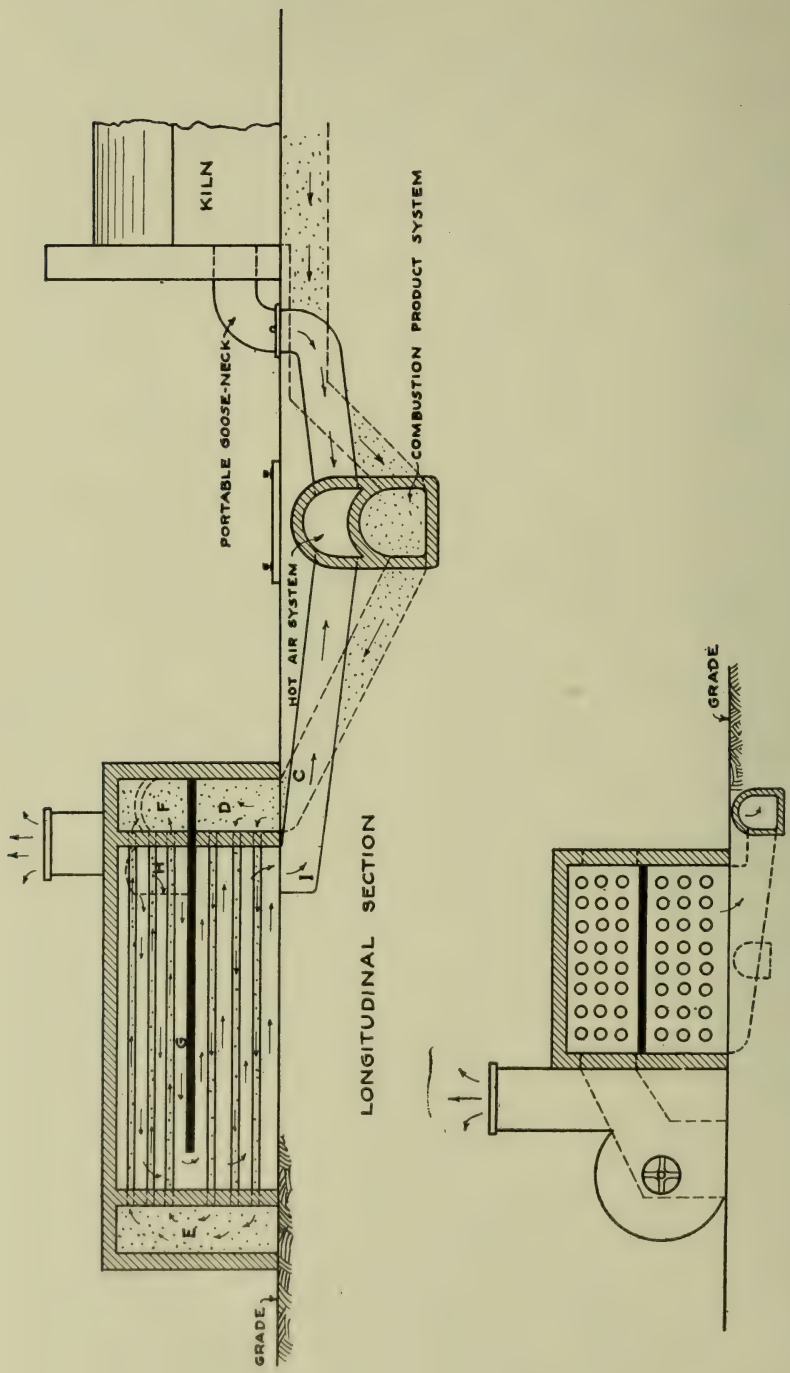

Fig. 147—Sectional Views of the Stove Used in the Groveport System.

it. By valves, the direction of the gases could be shifted at proper intervals, and the cool stove reheated and the hot one used for the air supply for the dryer. There is nothing about this plan which is not perfectly feasible from the mechanical standpoint, and well worked out in the daily practice of the blast furnace. The novel feature consists in applying the idea to a ceramic instead of a metallurgical problem. The only difference of operation between the two places would lie in the lower temperature at which the stove would operate in the clay works. Using kiln combustion gases from any ordinary battery of kilns, the temperature would hardly exceed 500 or 600° C. after leaving the kiln and reaching the stove by a more or less lengthy underground flue. These gases would then be cooled to 200 or 300° C. in passing through the stove, before being discharged at the exit end. At this temperature range, 500 to 200° C., there would be danger of sooting the surface of the checker-work of the stove, and if soot did deposit upon the checkers it would speedily defeat the purpose of the stove, as it is a powerful non-conductor. The stoves of the iron furnace are heated directly by the combustion of the waste gases of the furnace, and in each shift any soot deposited would become thoroughly burned out by the red-hot air flowing over it.

The general travel of the combustion gases from the kilns would be through the main flue D to the flues E, E, which in turn connect the chambers, A, A, of the stoves. As noted, the stoves are divided into three compartments, A, B and C, and so arranged that the gases would pass up through the checker work of chamber A to the top of the stove, thence downward through chamber B, under the partition wall and up chamber C to the fan G (see small sketch).

The draft fan, as noted, is placed upon a bridge between the stoves, and connected to each by suitable dampered flues. These flues in turn would be so constructed that when either stove was being drawn upon for heat, cold air would be admitted at the top and would pass down through chamber C, then up through B, and down A, thence out through flue F to the dryer fan and dryer.

While there are many possible ways to arrange the stoves and their flue systems and connections, the one suggested is the most simple and obvious one. If three or more stoves were to be used, some rearrangement would be needed, but the changes would all be easy to make and operate.

The strong argument in favor of the regenerative stove, for utilizing the waste combustion gases of burning kilns, lies in the fact that all parts of the stove coming in contact with the gases would be constructed of fire brick or tiles, thus preventing the destruction of metal parts as in the Groveport system.

There is no reason why the life of the stoves should not be indefinite; thus the first cost would be practically the only one. The fan at the

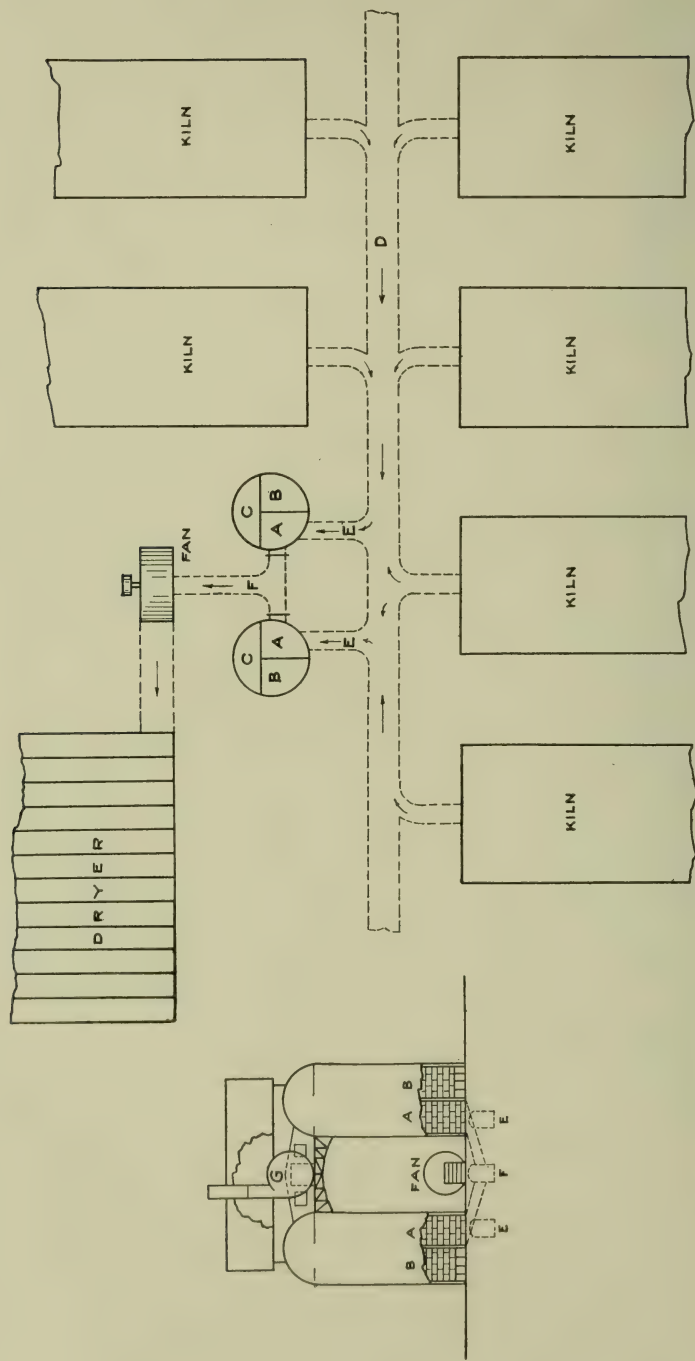

Fig. 148.—Sketch of Proposed Regenerative Hot Blast Stove Installation Applied to Drying.

exit end of the system would necessarily corrode from the sulphur of the kiln gases, but this would happen equally in any system where combustion gases are utilized, and it would be an item of minor importance in any case. It is hoped that this suggestion may be taken up by some clay works and tested. Its chances of success are best, of course, in a plant where a considerable number of large kilns are in use, so that there would be at least one kiln available at all times whose waste gases would be coming off at a temperature of 1,000° or above, reducing the sooting problem to a minimum.

The New Lexington Dryer.—This dryer (Figure 149) is the largest in any of the roofing tile plants of this country. The equipment was furnished by the New York Blower Company, Bucyrus, Ohio, whose drawings were largely used to make up the plans shown.

It will be seen that this dryer is of the double track tunnel type. There are at present thirteen tunnels, or twenty-six tracks. Each tunnel is eight feet wide, six feet high and one hundred and sixteen feet long, holding about thirty two cars of standard make. The ducts under the tracks are eighteen inches wide, and twenty-one feet or three car-lengths long. At the main flue they are thirty-six inches deep, and at the upper end twelve inches deep. The main cross duct is fifty inches by eighty inches, tapering to twenty-four inches by thirty-six inches at the ends. The main flue leading from the cross duct to the fan is eighty inches by ninety inches. The fan wheel itself is thirteen feet in diameter, with a six and one-half foot face, and it is driven by a forty horse power slide valve engine, direct connected.

This dryer is provided with a set of steam coils in connection with the waste heat, so that the drying can be done by either system, although waste heat is the one mostly used.

In Section AA it can be seen that between the fan and the steam coils there is an inclosed space provided with a damper. This damper, when down, shuts off the waste heat system, and when up it shuts off the steam coils. It can be operated so as to allow them both to furnish heat at the same time. In case cold air is needed for dilution, the coils being shut off, the damper is lowered to a point where sufficient cold air is let in to temper the hot waste gases to the proper degree. The dryer is generally operated at about 140° F., though it often runs above this at the hot end.

The main trunk tunnel, leading out to the kiln yard, is six feet four inches by eight feet, connecting to sixteen round down draft kilns, part of which are twenty-six feet in diameter and part thirty feet.

Other Dryers.—The Ludowici-Celadon Company, at Alfred, N. Y , has a waste heat dryer of ten double track tunnels in use. The equipment in this case was furnished by the Buffalo Forge Company, of Buffalo, N. Y. The tunnels at this plant are only seventy feet long, the drying being accomplished in twenty-four hours. At the New

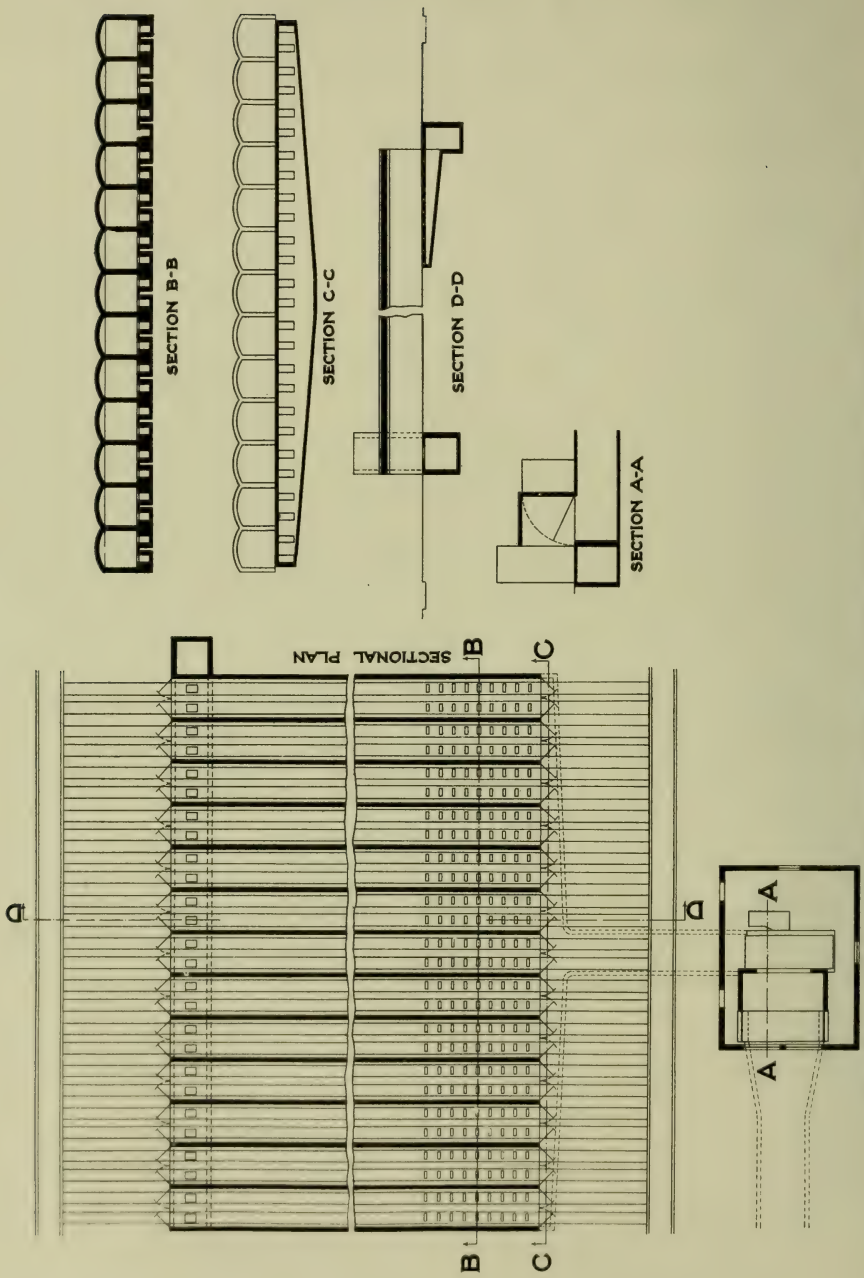

Fig. 149—Waste Heat Tunnel Dryer. Ludowici-Celadon Co., New Lexington, Ohio.

Lexington plant of the same company, the ware is from thirty-five to forty-eight hours in passing through the dryer. The time of drying, however, is regulated by the clay in use. The Alfred Clay Company, of Alfred, N. Y., has a small waste heat dryer consisting of four single track tunnels eighty feet long. The fan at this plant was furnished by The Buffalo Forge Company, of Buffalo, N. Y. The ware was being dried in twenty-four hours.

At the Western Roofing Tile Company, Coffeyville, Kan., the equipment for their waste heat drying system was furnished by the New York Blower Company, Bucyrus, Ohio. They use a small auxiliary furnace, fired by gas, to supply direct combustion products to carry them over times when no hot kilns are available.

In the above cut can be seen the waste heat fan and the gas engine for operating it at night. During the daytime the fan was run by a belt from the main line shaft as shown in the illustration. To the right of the fan can be seen a small furnace built of brick. The large pipe leading down to the furnace is the waste heat flue leading out to the kilns.

Claims for waste heat dryers:

First—That they will dry ware at less cost than any other style.

Second—The first cost is practically the only cost, except for the small cost of operating the fan engine.

Third—It makes a direct saving out of an otherwise total loss.

Fourth—It increases the kiln capacity by cooling them off faster, so that they can be reused earlier. This point is well worth considering.

Fifth—It gives better burns in the kilns, by carrying the heat more vigorously to the bottom at the conclusion of the firing.

SUMMARY.

The foregoing description of the dryers found in use among roofing tile makers brings home the lesson that it is unwise to condemn the equipment of any plant on purely academic grounds, until all of the local conditions are carefully considered. These conditions frequently explain, even if they do not wholly justify, the use of inefficient or poorly designed equipment.

It is, of course, impossible to prescribe the *best* dryer for the roofing tile business. But we may go so far as to say:

First—That for handling the terra cotta and trimmings, a simple room dryer, equipped with ample shelving or rack room, and with provision for maintaining pleasant work-room temperatures at all times, is all that is needed. The source of this heat should be from the waste of other departments, either by building the room above the general dryer, or by use of exhaust steam piping. It is not usually economical

to try to heat a work-room from waste heat of the kilns, unless the latter are located inside of a covered building and the radiations of their exterior can be thus utilized.

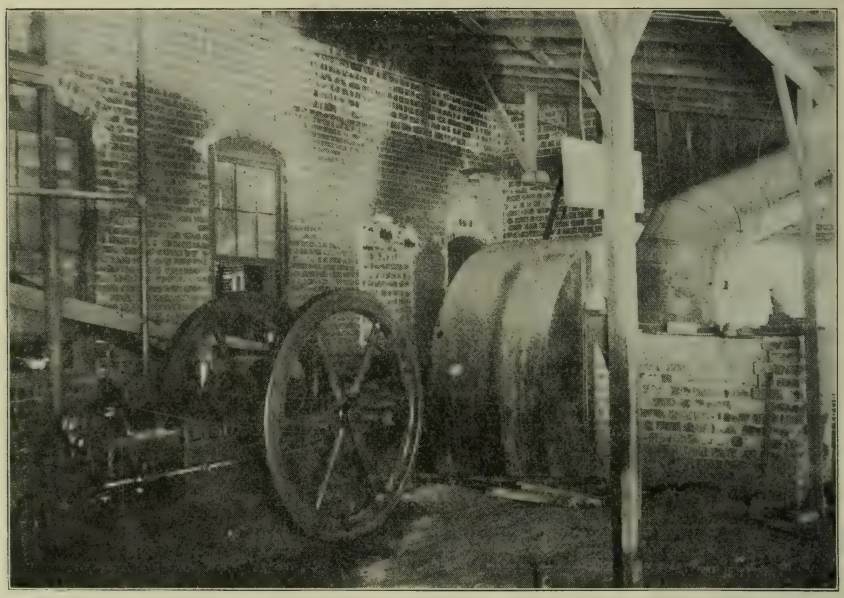

Fig. 150—Dryer Fan at Western Roofing Tile Company, Coffeyville, Kansas.

Second—As the source of heat for drying the regular output, the most convenient, elastic and positive arrangement, consistent with high fuel economy, is the use of the waste heat of cooling kilns as the main supply, employing the waste heat of the exhaust steam as the source when no kilns are available. The amount of fuel consumed purely for drying purposes would, with this equipment, be reduced to that necessary to run the fans, and supply such live steam at night as would be necessary in excess of the exhaust of the fan engine, and electric light engines when the latter are used. Such amounts would be small.

It would be possible to equip the kilns so as to utilize the waste heat of the combustion products for drying purposes, but this heat could be used more economically and effectively for water smoking other kilns, etc., rather than for drying. The danger in using combustion products for water smoking purposes, or for direct use in dryers, lies in cooling these gases below their dew point, and thus depositing acid dew upon the wares and scumming them.

Third—The form of dryer in which this most economical heat supply should be applied must depend on the clay. Where the latter is safe and easy drying, the tunnel system, operated as a continuous dryer, with both forcing and suction fans, gives the finest results both

as to speed, quantity and freedom from scum. With clays more or less tender, departure from this type to any required degree must be made. Usually a periodic tunnel will handle a moderately tender clay. If not, a room equipped with tracks will perhaps answer.

Fourth. In dealing with tender clays, the safety of the product is always first, and fuel economy secondary, and it is not to be expected that methods for tender clays will give any high-grade results as to fuel economy, for such methods involve small outlay, slow drying, liability to scumming, and extensive capacity in proportion to output, and hence expensive heat distribution and much heat loss.

Fifth. The use of new fuel, burnt for drying purposes only, with no effort to apply the waste heat of engines or kilns, and especially by such methods as the indirect radiation of hot floors, with no positive provision for creating or distributing draft, represents the lowest grade of practice, and is utterly unjustified on any grounds. The clay cannot require such treatment, for it is severe on a tender clay, and any clay that would stand this would stand better methods. Economy of first cost cannot be urged, for the dryer is expensive to build. Economy of operation cannot be urged, for it is the most costly to operate. Simplicity cannot be urged, for it requires more labor and as much management as a good dryer. In short, it represents only bad management and low intelligence.

Sixth. The selection of a plan of drying involves the consideration of the system of handling the ware: (a) from the machines to the dryer; (b) in the dryer; and (c) from the dryer to the kiln for setting. The economy of the drying cannot be considered apart from the handling system.

Seventh. The use of cars, or some sort of portable racks or pallets, rather than fixed racks or shelves, is consistent with even the tenderest clays, and should never be omitted. The extra handling alone in some roofing tile plants costs more than the whole drying ought to cost.

DRYER CARS AND PALLETS.

Pallets.—The nature of roofing tiles requires that they shall be well supported when first made or taken from the press, and this support must continue until the tiles are dry enough to handle.

All roofing tiles, coming from either auger machine or presses, are far too soft or pliable to retain their shape without the use of a pallet or form. It is not only essential that tiles be supported, but they must have enough freedom of movement to allow for shrinkage while drying.

The choice of materials for use in constructing pallets has been given much consideration and experiment in the various roofing tile plants. So far, wooden pallets have, on the whole, proven the most satisfactory.

on account of their cheapness, lightness, and strength. They also offer good resistance to sudden blows or shocks, if suddenly dropped or roughly handled. Other materials, including heavy sheet iron, cast iron, slate, and wire mesh, have from time to time been used. Some of these are still in use to a small extent.

Taking up first the pallets for flat shingle tiles, the most simple form of all, we find in use at the greater part of the plants the plain lath or wooden pallet shown below.

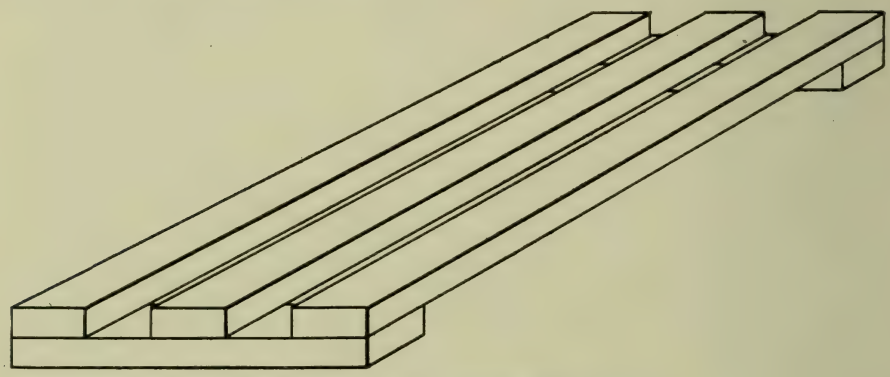

Fig. 151—Wooden Shingle Tile Pallet.

This pallet is best made of white pine or poplar. The two end strips or tie-pieces are about one-half by one and one-half inches, while the main top slats, three or sometimes four in number, are from one inch to one and one-half inches wide by three-eighths inches thick. The length should suit the tile, with about one-half-inch surplus at each end, to permit the necessary play while placing on the rack cars. The whole pallet is securely nailed, and costs in the neighborhood of four or five cents. Hence with pallets sufficient for a three days' run, allowing an output of twelve thousand per day, it will be seen that there is a considerable investment represented. Their rapid rate of deterioration makes it very necessary to get the best.

From time to time, a good straight slate of the proper size has been used, but it has been found very difficult to get straight ones, and the worst feature about them is the breakage which in a year's run is enormous. The high breakage makes them too expensive and their weight is objectionable. At the Huntington Roofing Tile Company, it was found that iron shingle pallets were being used. This pallet was six inches wide, about fifteen inches long and one-eighth-inch thick. Except as to weight, they make very serviceable pallets; they require very little space on the car or in storage, hold their shape well, and if bent can be straightened back again, so that their life is indefinite. For "curvilinear" tiles for domes, it is only necessary to have a number of them bent to the proper curve, and then put the tiles on

the same as though it were a straight pallet. While their first cost is a little above that of wooden pallets, their durability is very much better, and by keeping them protected with good metallic paint they will outlast the wood so much as to make their ultimate cost less than wood.

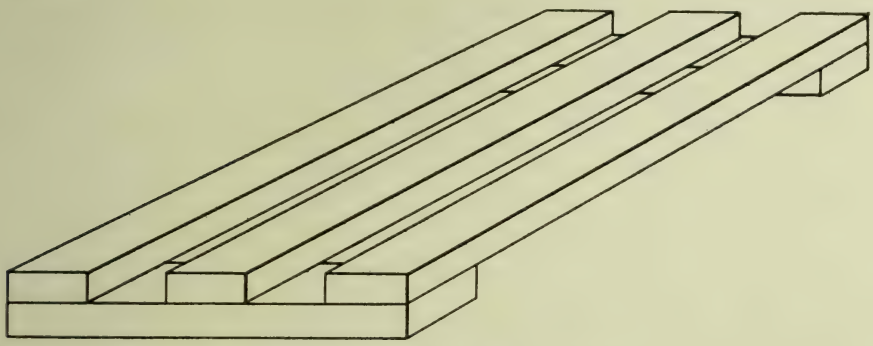

Fig. 152—Interlocking Tile Pallet.

Pallets for interlocking tiles are all practically of one style, viz., plain slatted wooden affairs, in various sizes to suit the tiles. With some designs of tiles, it becomes necessary to increase the thickness at certain points to support irregular parts of the surface and locks, but the main features of the pallets are not changed.

It will be seen in Figure 152 that the interlocking tile pallet is only an enlarged form of the shingle tile pallet. The slats or cleats are usually one-half inch or five-eighths inch thick, and two inches wide. The material is either white pine or poplar, well seasoned and surfaced on both sides.

During the days of the Chicago Roofing and Siding Tile Company, at Ottawa, Ill., a pallet like the above was used, except that the end cleats were put on edgewise, so that they formed legs. The pallets, when loaded with tiles, could then be stacked one above the other for drying. Their dryer was that of the slatted-floor type, commonly used in sewer-pipe manufacture, and the pallets were trucked into the dryer on two-wheeled trucks, and set off on the floor ten to twelve courses high. Hence legs were necessary. For drying on cars or racks, the pallets shown in the illustration are of the proper style.

The most trouble is experienced in providing a pallet for Spanish tiles which will not only hold the tiles true to their curves, but at the same time will allow them to shrink. The pallet shown in Figure 153 has proved the most satisfactory of all.

These pallets are very ingeniously constructed. They are made of a single base-board, about seven-eighths inch by twelve inches, cleated with two strips on the under side. On the left-hand upper side is nailed a strip of wood having a curve to correspond with the curvature of

the tile at that point. On the right-hand side are two strips, the inner one being nailed fast to the base, the outer one loose or movable. It is necessary to have this outer strip movable to allow for the drying

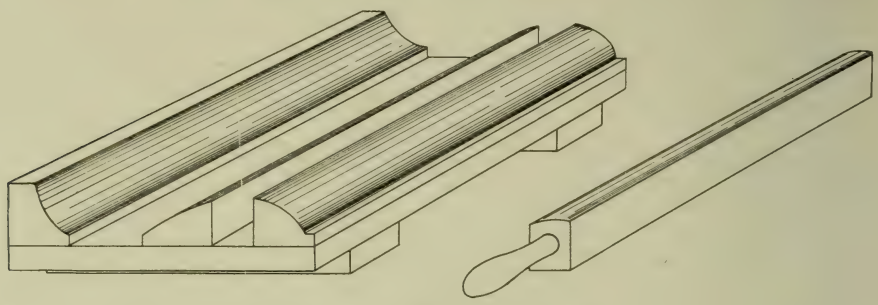

Fig. 153—Spanish Tile Pallet.

shrinkage of the tile. In order to hold the movable strip in the proper position while putting the tiles on the pallet, the false block to the right in Figure No. 153 is inserted, upon placing the pallet ready to be filled. After the tiles are placed on the pallet, usually three deep, the block is removed and the pallet with its load is ready for the dryer. In case the outer or movable block is made fast to the base-board, the tile will be spread or flattened out at that point. If not flattened, they will crack lengthwise of the tile.

Metal pallets of this same general outline have been used, but it was found that they soon lost their shape, and, also, no provision could be made to allow for the shrinkage. Hence, many of the tiles were spoiled in the drying.

For Spanish tiles made on presses, it becomes necessary to construct a pallet which will allow for the head or heel locks of the tile. It will be seen in Figure 154 that this pallet is copied after the form used for shingle and interlocking tiles. The only real difference is that the right hand slat is made enough thicker than the others to hold the roll of the tiles at the proper level, and a slot or groove is cut crosswise of the pallet to provide depth for the heel lock. This slot is made about twice as wide as the lock lug, so that ample room is given for shrinkage.

Each plant finds it necessary to have many other pallets than the ones used for the regular tiles. There are pallets for eave tiles, top or ridge tiles, mitre tiles, tower tiles and various other shapes, all of which must be provided for specially. The number of any one of these special forms is not very large, but the aggregate is very considerable.

Dryer Cars.—The question of dryer cars has been worked over about as thoroughly as the matter of pallets. Natural selection has reduced the surviving types to about two forms, both of which are rack cars. On one, the cross racks or strips are movable or loose, while on the other

they are fixed. A rack dryer car, to meet the demands of a roofing tile plant, must be easily adjustable to suit the various spacings needed for the many sizes of tiles made.

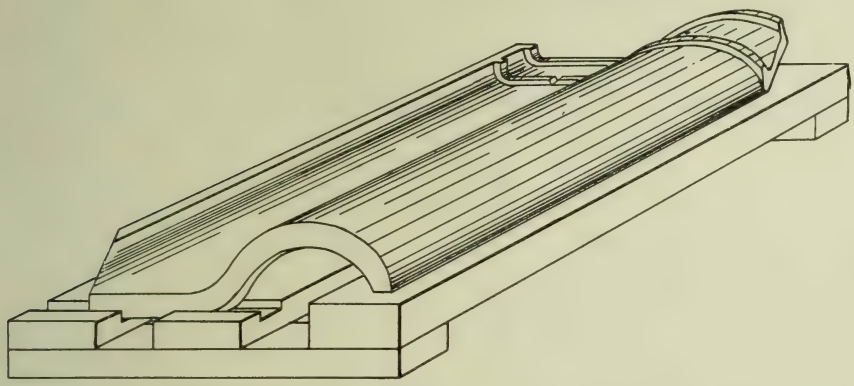

Fig. 154—Pallet for Press-made Spanish Tile.

There are in use at the present time in the various roofing tile plants of the country about two thousand five hundred cars, the greater part of which have been made by standard car builders. Among them were the following First, The Cleveland Car Company, Cleveland, Ohio, having the largest number in use; second, The Atlas Car Company, Cleveland, Ohio, with the next largest number in use; third, The Ohio Ceramic Engineering Company, Cleveland, Ohio; fourth, The American Clay Machinery Company, having cars in two plants. Two roofing tile plants have built or assembled their own cars.

The average dryer car for roofing tile is of twenty-four inch gauge, the rack is thirty-six inches wide by seven feet long and a height over all of about six feet.

The racks are divided either into two or three sections. The number of shelves that are put in a section depends on the tiles manufactured, most of the cars holding from one hundred and fifty to two hundred interlocking tiles, or two hundred and fifty to three hundred shingle tiles.

The main truck of this car may be of any make. The uprights are of narrow channel iron, usually two inch, and are riveted to the truck, and secured by gusset plates as shown. At either side of the top, a longitudinal tie bar of iron fastens the uprights together, while at the ends it is usual to put on cross braces, as shown by the end view.

Running across the car, from upright to upright, and riveted to the same, are one inch angle irons which act as brackets upon which the one inch wooden strips rest. These wooden strips are loose so that upon loading a car at the press, the strips on the side nearest the press are left out, thus allowing the placer to reach more easily the opposite

side of the car with the pallets. When the further side of the car is filled, he puts in the strips on the near side and fills them. It is usual to have about three rows or tiers of pallets, running crosswise of the car, so that it would be difficult to reach through and put the further row in place.

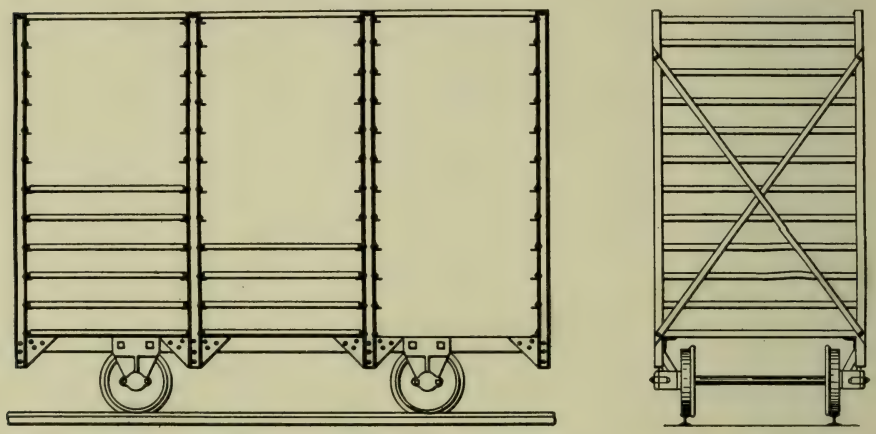

Fig. 155—Three-Section Dryer Car, with Loose Racks.

The objection to this style of rack system is that there are too many pieces to handle, not only at the press, but in the kiln. This point has been overcome by some in having two section cars with strips reaching the full length of the car. The trouble in this case is that the strips cannot be taken out of the car without pulling them out from the end, which takes up much time.

Probably the best style of rack car, where loose strips are used, has a rack containing loose sections, and has the strips reach half the length of the car. They can then be easily taken down, or put up, as occasion requires.

Where a plant is running continuously on one style of tiles, a rack car can be devised, as has been done by the Ludowici-Celadon Company, at New Lexington, Ohio, which comes very near meeting all requirements. In this car the strips are fixed.

It will be observed that this car is constructed much like the one just described. The upright members are made of channel iron, well braced and riveted. Instead of the one inch angle irons being fastened to the uprights, and forming supports for wooden strips, they are carried by two inch channel irons extending lengthwise of the car on either side.

The one-inch angles are held in position by having a short section of pipe put under the top leg, to act as a spacer. The rivets which hold the angle pass through the pipe washers also, making a very solid, well

built car. The pallets are slid in on the one-inch angles, the first one being put in part way, then pushed over by the ones following. The pallets are put in four wide, filling the width of the car.

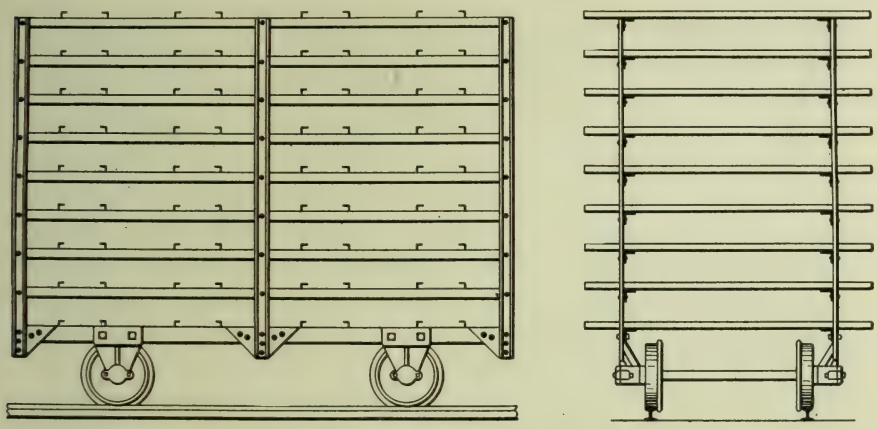

Fig. 156—Two-Section Dryer Car with Fixed Racks.

In the case of the car having loose slats, the tiles are placed crosswise of the car, and hence at right angles to the flow of air in the dryer, while in the car having tight slats, the tiles are placed so that they are lengthwise of the car, hence the flow of air in the dryer passes lengthwise of the tiles and not across them. This latter plan is probably the better, for the ends of the tiles are more able to stand unequal strain from sudden drying than the sides.

The main objection to the car with fixed racks is the inability to adjust it to suit the various styles of tiles made about the plant. If sufficient cars can be supplied to handle all necessary varieties, it is much better to use fixed racks. The value of a dryer car will vary materially with the style and the kind of rack wanted, but a fair average price is about $20.00 each.

In selecting a car the bracing and the rack construction should be well looked to. The axles should by all means be equipped with roller bearings and automatic oiling facilities. The roller bearings should be made of true, perfect cylinders or rollers. The kind that are sheared from rod iron or cast, as are used on the cheaper cars, are very unsatisfactory. The sheared roller is sure to be flattened at the ends, from the pressure of the shears in cutting, and hence they can not run easily. The boxing should be such that the oil cannot escape as soon as it becomes warm in the dryer.

The entire car should be well coated with a good metallic paint, especially if the cars are to be used in a waste heat dryer, for the corroding action of even diluted sulphuric acid while in the damp atmosphere of the dryer is very severe on unprotected iron.

It can be positively stated that roofing tile companies cannot make their own cars as cheaply, or as well, as the firms that are making cars all the time. In the first place, no ordinary clay works has the proper

Fig. 157—A Home-made Car.

tools for doing the work. Their men are not skilled in such labor. A plant may be able to save a trifle on the first cost of the cars, but the loss comes in later in the short life and extra labor to use the car. In other words, every man to his trade, and always at it.

CHAPTER VIII.

SETTING OF ROOFING TILES.

The first thing to consider in connection with the burning of a clay ware of any sort is the proper mode of placing the ware in the kiln so that each piece may receive the heat treatment necessary to develop its strength and color and at the same time not be damaged by sinking out of shape under its own weight.

The process of placing is universally known as "setting" in the United States, and it is one of the most important things which a successful clayworker has to consider. The difference between expert setting and ordinary setting may easily make the difference between success and failure of a whole establishment. It is a place where craftsmanship counts very heavily in any clay working enterprise. The problem of setting roofing tiles is more akin to that of setting terra cotta or pottery than it is to bricks, sewer pipes or other crude forms of ware. The distinction hinges on the question of the ability of the ware to sustain weight. In the case of bricks or pipes the ware is self-supporting. Bricks, being of thick, heavy cross-section, are admirably designed to support great weights, even when approaching viscosity by vitrification. Bricks are set twenty-five to thirty courses high, without any supports whatever when firing to vitrification. When firing only to good building brick hardness, forty-five or even fifty courses are piled up without supports. This corresponds to a crushing pressure of from twenty-five to thirty-five pounds per square inch on the lower courses, owing to the uneven distribution of the load, and to the fact that all parts of the bricks are not carrying weight. This load must be borne not only by the dry bricks, but also when the bricks are softened by steaming in the water-smoking stage of burning and when softening from heat during vitrification.

Sewer pipes are usually placed four or five tiers high, with about one-half of the above pressures, but their shape is less favorable for resisting pressure.

In the case of wares of thin cross-section, like roofing tiles, it is impossible to make the ware carry its own load after the manner of bricks, provided it is desired to develop any great amount of vitrification in the firing. Warpage and deformation are certain if the tiles are so placed that they are free to move and are called upon to bear any but trifling weights. Some forms of roofing tiles which are not vitrified can be treated more roughly than the average.

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The methods employed in setting roofing tiles may be divided into three general classes:

1st. Those using kiln blocks for supports.

2d. Those using no supports.

3d. Those using saggers.

There were eight plants using the supports, and five plants were found using no supports. One plant, now defunct, had been using saggers. The plants not using supports are making porous or soft-burnt tiles only.

SETTING WITH KILN BLOCKS.

Blocks.—The blocks used for kiln furniture in the roofing tile business are most usually made of No. 2, or easily vitrifiable fire clays. Sometimes, to make them harder, so as better to resist handling, various per cents of ordinary red burning clays are added.

In dimensions the blocks are, of course, made to suit the sizes of tiles manufactured. The thickness of the block is usually two and one-half inches, remaining the same for all sizes. The blocks mostly used for Spanish tiles are eleven by fifteen by two and one-half inches. For shingle tiles the horizontal blocks are as a rule the same as the Spanish blocks, but the risers, or uprights, are seven by eleven by two and one-half inches if the shingle tiles are six inches wide and are set on edge.

While some of the roofing tile plants buy fire clay and make their own kiln blocks, it is in most cases better to purchase the blocks from the fire brick companies that are fitted for handling this class of work and this is most commonly done. On inquiry, The Chas. Taylor Sons Co., Cincinnati, Ohio; The Harbison-Walker Co., Portsmouth, Ohio; The Stowe-Fuller Co., Cleveland, Ohio; the Federal Clay Products Co., Mineral City, Ohio, were found to have supplied the bulk of the blocks used by the roofing tile manufacturers, but the ware is of a kind that any fire brick manufacturer could readily supply.

The kiln block should be well made; it should be straight, with sharp corners well filled out, true to size, and burned to a point where it will stand rough usage without undue crumbling along the edges. These blocks are not destroyed by the heat they are called on to endure, but by the constant handling in setting up and taking down each time the kiln is fired.

In preparing a kiln for setting, should it be a new one, the first thing done, starting at one side in round kilns or the end in rectangular kilns, is to place ordinary fire bricks in rows upon the floor of the kiln. The first row is placed about three inches from the wall or end of the kiln. Each individual brick is placed on its side, and is so spaced from its neighbor that the kiln blocks to be used will reach from the center of one to the center of the next. This will leave five or six inches be-

tween the ends of the bricks. They are thus continued across the kiln. A parallel row is placed so that the surfaces of both rows will be covered by one of the kiln blocks. After both rows of bricks are down, blocks are then paved on them from end to end. (See Figure No. 163.)

After the first stand is laid out, a five or four inch space is left, and a second stand is put down parallel with the first. In this manner the entire floor space of the kiln is laid off. The object of this false floor is to elevate the position of the lowest tiles above the main floor, so that they shall not be cut off from contact with the currents of hot gases as the latter are deflected over the floor in finding a passage out. Ware set on the actual floor would be apt to be spotty and irregularly burnt.

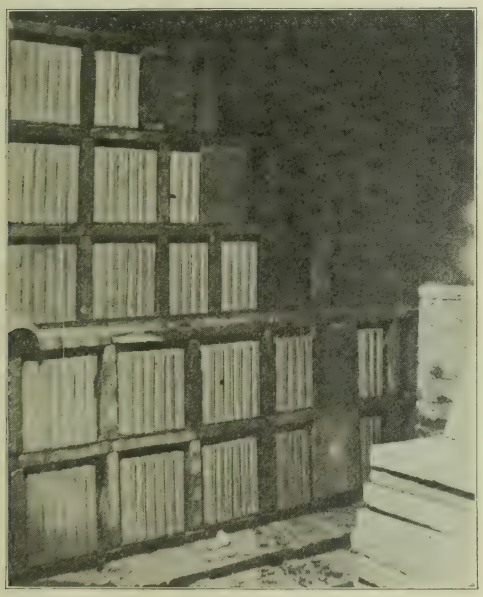

Fig. 158—End or Bench Braces in Round Kiln of Spanish Tiles.

The setter now stands a riser block on the first stand of bottom blocks, and against the left hand wall of the kiln. Then he places tiles, which are handed to him two at a time, against the riser block. After the required number have been placed in a pile, a second riser is put in at the point where the two floor blocks meet (see Figure No. 163), and a cover block is laid across, connecting from the center of the first riser to the center of the second. The rectangular space thus created is called a "box." A second box is made and filled, using the second and third risers and a cover tile. Thus the work proceeds.

A vertical tier of boxes, reaching from the floor to the top of the setting, is called a bench or stand. The latter is the better name, as "bench" in other clay industries refers to a horizontal division, not to

a vertical one. When the first stand reaches a level where the setter can no longer conveniently reach to put on more boxes, he starts the second stand. After one or more courses of boxes has been placed across the kiln in the second stand, the setter uses this as a platform to carry up the first stand still higher, and so on, until the kiln is filled.

In round kilns, at the intersection of the stands with the walls of the kiln, it becomes necessary to put in braces against the stands at each course, to keep them steady and from toppling over endwise.

It will be seen from the figure that these braces are made by using two kiln-blocks, turned at right angles to the other risers, at the beginning of the last box. Considerable space is thus lost, but it affords a secure way of holding the risers in place.

To hold the benches from reeling or falling over sidewise, no provision is made except to keep the stands perfectly plumb, so that no tendency to fall is developed.

The foregoing gives a general idea of the method used in most roofing tile works. It will be found that the various styles of tiles, shingle, interlocking and Spanish, require some modifications of treatment due to their form and there is some element of choice also; i. e., shingle tiles are sometimes set in different ways.

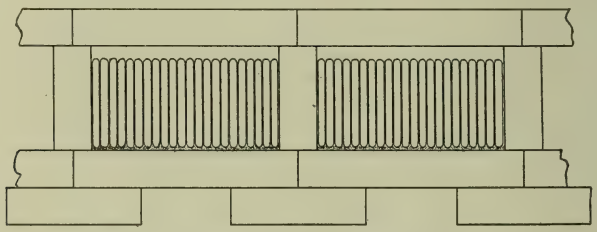

Fig. 159—Ordinary Way of Setting Shingle Tiles.

Setting of Shingle Tiles.—The setting of shingle tiles appears to the outsider the easiest and safest of all, but in setting, as in manufacturing, it is about the most difficult. The actual handling or placing is easy and simple; the skill comes in knowing the best method of placing to prevent side-checks, center-marks and warpage. There is, however, no single best method. One plan will best suit one clay, and an entirely different one some other clay. In the majority of cases, the plain ordinary setting shown in Figure 159 is used, on account of its simplicity and cheapness.

The tiles are placed in the boxes, on edge, and packed as tightly together as possible. It is necessary to pack them snug, in order to prevent them from leaning over sidewise as the shrinkage takes place. In some instances, a little sand is scattered under the tiles to assist them in drawing together during shrinkage, but more frequently the blocks are left bare.

While this style of setting tiles is largely used, it has certain objections:

First. The packing of the tiles in this manner makes to all intents an almost solid block of clay, six by twelve by fifteen inches. If a really solid block of clay of the above dimensions were to be burned,

Fig. 160—Showing High Shrinkage in Boxes of Burned Shingle Tiles.

it would be considered a very difficult task, and very truly so. It is also true to nearly the same degree with a mass of shingle tiles, set solid. Many of the standard roofing tile clays have been shown to contain considerable amounts of carbon, which must be very carefully burned out, at low temperatures. The thicker the individual piece or the more solid a group of pieces, the more difficult does it become to get rid of this carbon from the center of the mass. The best burning temperature for this carbon is at a rather low, clear red heat

(750° to 800° C.), 1380° to 1470° F. Higher temperatures increase the danger of center-marking, and lower temperatures delay the process unnecessarily.

A second difficulty is that of securing contemporaneous shrinkage in large masses. As the temperature increases, the top of a block of tiles (in a down-draft kiln) will become hotter than the bottom or center of the mass. Therefore the shrinkage will start first on top, and unless time be given to allow the heat to soak into the block of tiles side-checks will result.

A third trouble with this method of setting is caused, especially in clays of high shrinkage, by the tiles becoming separated and leaning over as the shrinkage takes place. It is not unusual for the shrinkage to amount to a full inch in a single box, so that the deflection of the tiles from the vertical is sufficient to allow them to warp or twist.

In the case of a clay low in carbon, properly prepared, and of not excessive shrinkage, it is perfectly possible to burn shingle tiles in this manner of setting in perfect safety.

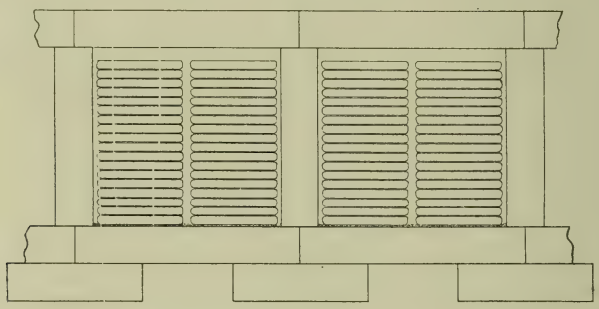

Fig. 161—Method of Setting Shingle Tiles Flat, in Use at Murray Roofing Tile Company, Cloverport, Ky.

The flat method of setting shingle tiles is shown in the above illustration. The mass of tiles is set flat, one on the other, instead of being set on their edges. Two blocks are set in one box. This method of setting was in use at the plant of the Murray Roofing Tile Company, Cloverport, Ky., at the time this plant was visited (July, 1908). While there are some good features about setting shingle tiles in this manner, there are at the same time some bad ones.

In the first place, the block upon which the tiles are placed must be perfectly straight, or sand must be provided upon which to bed the tiles. This method of setting is faster than the edge setting. Less kiln blocks are used, and no attention need be given to keeping the tiles from falling over. The fact that both edges of the tiles are exposed to the kiln gases, makes the liability to side-check less than by setting on the edge, in which case the upper side is sure to heat much faster than the lower.

The danger of center-marks is for the same reason a trifle less, but it is still great. One of the strongest points in favor of this method of setting is that the tiles upon reaching a fair state of vitrification will have a tendency to straighten out any slightly warped or bent tile by their own weight. Increase of the temperature increases the danger of warpage where the tiles are on edge, but decreases it as the heat increases in the flat-setting method.

If the tiles happen to be already warped when piled or blocked up, it will be found that considerable breakage will result from the weight on the warped members.

With nice straight tiles, and clay of average quality or above, this method of setting is unquestionably the best of any seen for shingles. It takes, however, ten or twelve days, from the time of lighting the fire to closing down, to safely burn a kiln of tiles set in either of the preceding ways, while other shapes of tiles can be burned in half the time or less, because the setting is more open and free. The relative tonnage per kiln would be much in favor of the shingle tiles, and when the fuel consumed in firing two or more kilns of other shapes in short burns is balanced off against the quantity of fuel consumed in firing the shingle tiles in their long burn, the probability is in favor of the fuel consumption per ton being less for the shingles.

On the other hand, on account of the heavy overlap of shingles it is likely that the fuel cost per square would be heavier than for interlocking or Spanish shapes.

Another method of setting shingle tiles has been used to some extent in a few plants, where it has been desired to burn shingle tiles in the same kiln with other styles, or, in other words, to hasten the time of burning. The plan as used a number of years ago was to set the shingles only on the top of the stands or benches, and not in boxes. Starting at the side of the kiln, on top of the stand, the first shingle was placed flat on a light bed of sand. The next shingle was placed in the same manner as the first, parallel to it but with an intervening space of about four inches. The third tile was placed in the same way, and so on, clear across the kiln. Upon reaching the further side, the setter returned and placed a second layer of tiles over the first, but instead of stacking the tiles one on the other, they were placed so as to cover the spaces, each tile overlapping the edges of those beneath by about one inch. The setting continued thus until ten or twelve layers had been laid down. A couple of tiles were lost on each course owing to "stepping in" the ends.

This method had some very good features: First, the tiles were set very open, allowing the kiln gases to circulate among them very freely. There was consequently no trouble from center marks, as the central area of each tile was exposed; second, the chances for side checks were reduced to the minimum, as the sides overlapped and car-

ried the weight, thus forming the thickest part of the setting, which would naturally shrink more slowly, thus giving the center of the tile the advantage and creating a tension there, rather than on the edges.

The objections to this method of setting are, first, only a limited number of tiles can be placed in each kiln (twelve to fifteen courses); second, being at the top, they were exposed to the direct flash of the flames, and many were lost by flashing and overburning.

An outgrowth of the above method of setting shingle tiles has been shown in the following cut.

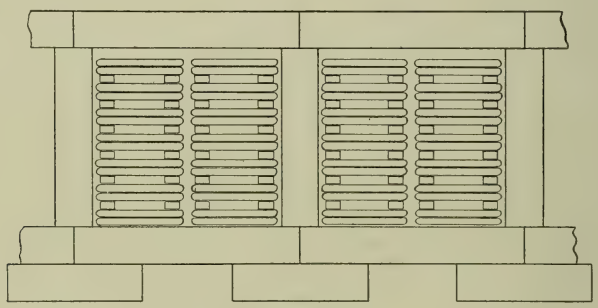

Fig. 162—Waste-Strip Method of Setting Shingle Tiles.

It will be seen that this method is a combination of the second and third methods, with the difference that straps, or narrow strips of newly made shingle tiles, are used as spacers.

The setter is provided with a trowel and a pallet full of tiles fresh from the machine; with the trowel, he cuts the narrow strips which he places as shown, lightly bedding each pair of tiles down, as he places them on the straps. Slight irregularities of the tiles are thus taken up by the yielding of the damp straps.

The advantages and disadvantages of this system are obvious: The dangers of side checks and center marks are obviated as in the previously discussed methods. The time of burning is greatly shortened from that required to burn shingles set in the ordinary way. And, of great importance, the entire kiln can be set with shingle tiles if necessary, or only portions, as may be desired. On the other hand, it is the most costly method of setting shingle tiles, as it requires so much time to cut and place the straps. The straps also consume heat, and are a loss at the end of the burn. The only use that readily could be made of them would be to grind for grogging the body.

About one-third of the space is lost in each kiln by the use of straps, which runs up the fuel consumption per ton. Lastly, the drawing or unloading of the tiles from the kiln is more costly, it being necessary to separate the tiles and straps. Many of the straps are badly checked or broken into short lengths. These pieces fall to the floor and get into

the flues of the kiln, thus causing extra expense in cleaning out the kiln bottoms oftener than would be otherwise necessary.

For the general manufacture of shingle tiles, this method of setting could hardly be recommended. In special cases, where only a few shingles are required to go with other styles and must be burned at the same time, it is certainly the most secure method of getting a high yield and good quality. The additional cost is to be endured under these circumstances.

Setting Interlocking Tiles.—There is practically only one way of setting interlocking tiles, viz.: in the "boxes" previously described, as built from kiln blocks. The method is very similar to that of setting flat shingles on their edges or sides.

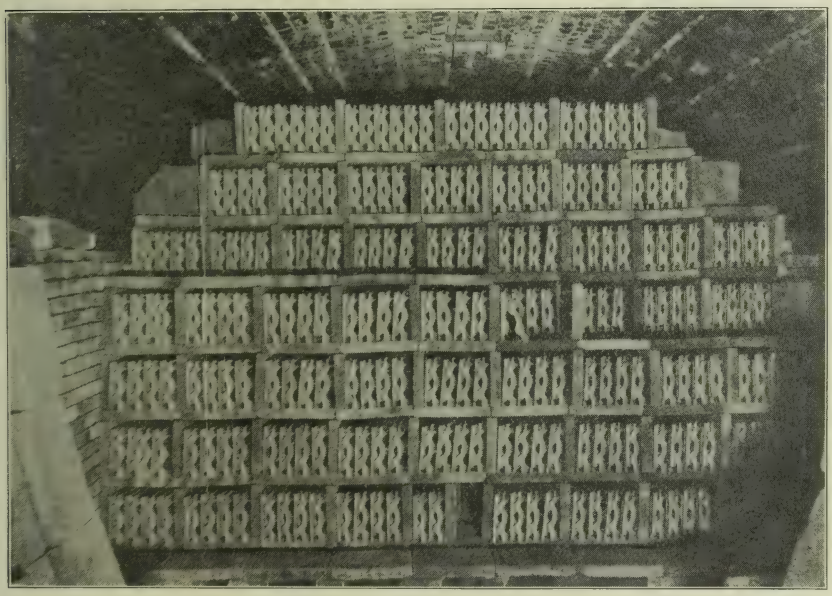

Fig. 163—Kiln Partly Set with Interlocking Tiles, Western Roofing Tile Co., Coffeyville, Kansas.

The interlocking tiles, however, are nested by reversing every other tile to make them fit more snugly together, i. e., the head lock of one tile is turned to mesh with the heel lock of its neighbor. All interlocking tiles are handled in this way in pairs, from the time they are dry until they are shipped.

By referring to Figure 163, it will be very easily understood how the tiles are set. The illustration is of a rectangular kiln; below the top of the bag walls no side braces are necessary to support the benches. Above the bag walls extra heavy blocks made for the purpose are used.

It is readily seen that in tiles with as much open space between them as the interlocking must have, very little if any trouble will result

from center marking or slow oxidation. For the same reason, and also on account of the shape, side checks are almost unknown.

Setting Spanish Tiles.—In setting Spanish tiles, there are two methods, one for auger machine tiles, and the other for the pressed tiles. While the setting is not widely different, the auger-made tiles require more care and experience. The auger-made tiles do not have the end locks or ribs, so they are much more apt to warp or twist. The locks very materially strengthen the press-made tile.

By referring to Figure 164, the general method of setting auger-made Spanish tiles can be seen at a glance. The tiles are placed on end in the boxes, in pairs, a narrow space being left between each pair. If the tiles were set tight, it would make a cubic mass of clay 11 x 12 x 14 inches, which would be very difficult to burn safely.

It has been found by experience, that for most clays, it is not safe to stand the tiles directly on the kiln blocks. Some cushion or yielding material must intervene. Should the tiles be placed directly on the blocks, the lower end of the roll will be flattened or spread out during the burning. This trouble comes from the inability of the tiles to shrink freely. It will be remembered that precautions have to be taken in drying this kind of tiles to prevent the same trouble there.

The liability to spreading of the rolls of the tiles, during burning, will be more intensified if the tiles are not set perfectly plumb. If a tile leans, it will throw more weight on the corner, or roll, and thus cause it to spread more. By placing a blank (called a strap) of damp clay on the block before setting a tile, the trouble is usually entirely obviated. The straps that are used are flat pieces of the same clay as the tile, about five-eights of an inch thick by eleven inches wide and fifteen inches long. These blanks are run at such times as is necessary to have them fresh; they must not be too dry, or they fail to accomplish their end.

In operation the setter places a strap on the bottom block of the box to be filled. As the tiles are passed to him, a pair at a time, he carefully stands them, as shown in the cut, against the last upright block. The next pair of tiles is set about one-half inch from the first pair and so on until the box is filled. The soft strap underneath makes it possible for the setter to get each pair of tiles vertical. Should the end of the tiles be irregular, it will be taken care of by the pliability of the strap. By examining the cut closely the straps can be seen under the tiles.

When the tiles have all been carefully set in the box, the setter takes an extra strap, and cuts three strips one inch or more wide from it. These strips, also called straps, are equally spaced across the top ends of the newly set box of tiles. With a trowel they are spatted down, so that they mesh into the openings between the tiles to a depth of one-fourth inch or more. This is done to hold the tiles at the proper distance

apart, and to prevent them from leaning or falling over, as they otherwise would be very likely to do.

When the kiln has been burned, the tiles and straps separate very easily; no trouble ever comes from this source.

At different times sand has been tried to take the place of the clay straps, but it has not been successful. The movement of the kiln gases will draw it away from under the outside corners of the tiles, and allow them to sag. Also, the sand very soon chokes up the kiln flues.

While the making and using of straps is an added expense, it is necessary, because it has been found next to impossible to burn the tiles safely in any other way. With clays of exceptionally low shrinkage, or where the vitrification is not carried very far, it may be possible oc-

Fig. 164—Setting of Auger-made Spanish Tiles. Cincinnati Roofing Tile & Terra Cotta Co., Cincinnati, O.

casionally to avoid their use. The setting of press-made Spanish tiles differs from that last described in that straps are not used. The tiles are placed on end in the boxes, with the top end down. The first one is set as tight against the riser as possible, the second is set tight against the first, and so on until the box is filled. The next riser is then put up, the cover block laid on, and the setting of the next box begun. Nothing is used to bind the tiles together.

In some cases, where the shape or locks of the tiles will permit, they are nested in the box, with every other tile reversed, end for end. This, however, will depend on how they will nest best, the complete utilization of the space being the object in view. It is impossible to set press-

made Spanish tiles so tight that they will center-mark. At best they are rather bulky in the kiln; it is impossible to set more than about two-thirds as many tiles in a given space as can be done with the auger-made Spanish tiles.

The reason that press-made tiles do not need to be set on straps is that the strong lugs, or locks, on the ends stiffen the rolls of the tiles and prevent their warping.

SETTING ROOFING TILES WITHOUT KILN BLOCKS

As stated before, there are five roofing tile plants that are setting their ware without the use of kiln blocks, saggers or other means of support.

In foreign countries this method of setting is used almost exclusively; the use of supports is familiar to them, but they do not care to make much use of this plan. In the European plants it is the general practice to burn their product only till it is weather proof, and their ware is what is called in the United States "porous" ware. It is therefore quite possible to set such ware without supports. If producing real vitrified ware, such as many of our American plants are doing, they would be compelled to use kiln blocks or other supports.

The situation as explained for European plants is exactly the case with the five plants in this country that are not using supports. They are all producing porous ware, and they could not set their ware as they do if it were to be carried to anywhere near complete vitrification.

By examining Figure No. 165 it will be seen that on the floor of the kiln are placed three courses of fire bricks, cross-hacked and very open. This is to allow the hot gases to distribute over the floor more evenly.

Beginning on these bricks, the tiles are placed on their side in packs or bunches of ten each. The first pack is parallel with the kiln walls, the next pack is reversed, and so on. It is necessary to wedge them tight at the side of the kiln, so that there can be very little chance of their rolling.

Upon starting the second course, the first pack is turned at right angles to the pack below it; thus every other pack is alternated from bottom to top, as well as from side to side. The ends of the tiles in the separate stands come close together, so that the chance of rolling in this direction is also reduced. In the case shown the tiles are set eight courses high. The spaces between the bags are filled by reversing the direction of the rows, as can be seen behind the man on the left side of the illustration.

In drawing the kiln, the bricks on the floor are taken up and piled in the spaces between the bags after the tiles have been removed. Thus

Fig. 165—Kiln of Interlocking Tiles Set without Supports, National Roofing Tile Co., Lima, Ohio.

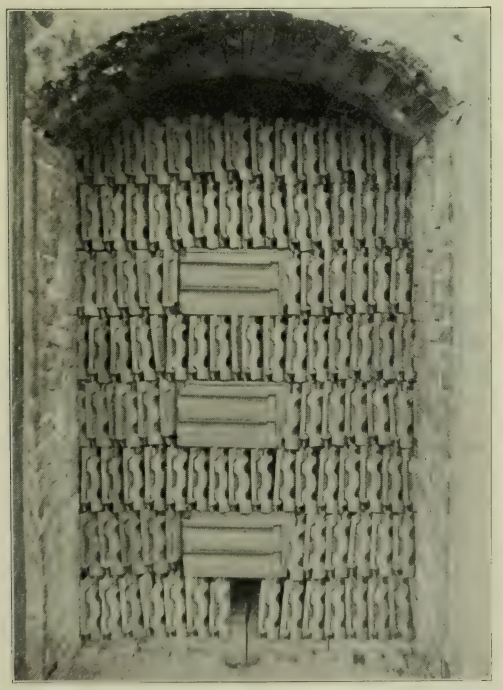

Fig. 166—Doorway of Kiln Filled with Interlocking Tiles, Ludowici-Celadon Co., Ludowici, Ga.

they are out of the way of the cars in setting, and are placed only as fast as new stands are to be begun.

In this plant it will be seen that the tiles are set directly upon the floor. The small opening at the floor line is the "peep hole" for observing the heat distribution and for draw trials or cones. It will also be observed that very few tiles are reversed—just enough to steady the benches. Where it is desired to burn glazed ware and is necessary to keep the ware from sticking together, a combination of the two methods is employed. The glazed ware is placed in boxes in the lower part of the kiln, and the open setting without supports is used for the unglazed wares on top of the boxed courses.

In this case, shown in Figure 167, fire bricks have been edged on the floor of the kiln, and upon them boxes made of rectangular fireproofing blocks have been placed. The boxes extend down both sides of the kiln, and then across the kiln with each bench.

The regular setting, without supports, begins on the top of the boxes, and continues six courses high. Tile-packs set crosswise for braces are placed about every twenty tiles. The tiles which are placed directly over each other are not exactly parallel with each other, but are set at slight angles, reversing with each course. This mode of setting is similar to what is known as "skintling" in brick setting. It avoids any opportunity for the tiles above crushing down between those below, and also prevents sidewise rolling in the stand.

SETTING OF ROOFING TERRA COTTA.

The roofing tile manufacturer, as a rule, sets his terra cotta trimmings in the odd space that is left after the kiln has been set as compactly as convenient with the regular shapes. This extra space is most usually found on top, where the terra cotta is exposed to the most severe heat treatment, and where it is most likely to be ruined. This ware, which has cost the most to make of any produced in the plant, should be given the most favorable opportunity to pass through the kiln safely, rather than the least favorable.

The reason that the terra cotta is as a rule placed on the top of the benches is on account of its large size and irregular shape. Hip rolls and much of the cresting can be set in the ordinary boxes, but often at great loss of space. The finials are too large and ungainly to go into regular boxes, and therefore are placed on the top.

The method of setting finials is clearly shown in Figure 168. They are placed on the flange or cresting end, and the ball or head is supported by the low pile of kiln blocks or brick, with a damp strap of clay on top so that the finial can shrink freely. Gable finials stand on end. Special shapes and odd ware has to be set as best it can. An effort should always be made to support it equally in all parts. Large tower finials

are always burned with the bell up, and the small end down, the supports being built up under the bell.

Instead of placing the terra cotta on the top of the kiln, it would seem the rational thing to provide large kiln blocks of a suitable size to accommodate it, and then set these large boxes in the center of the kiln where the terra cotta would get the most favorable treatment. In fact, this is being done at one plant at the present time.

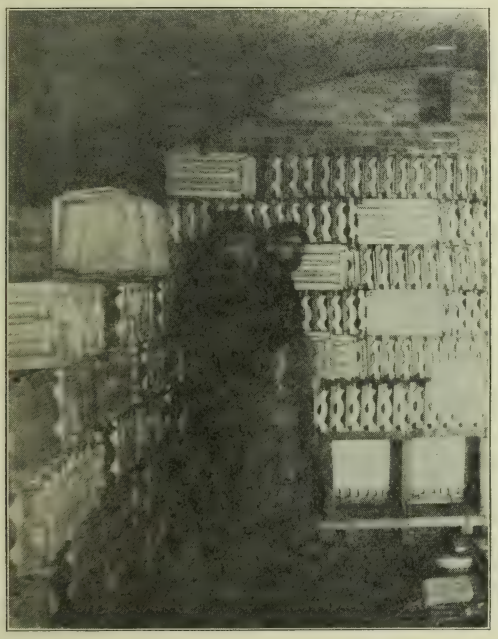

Fig. 167—View in Kiln at Detroit Roofing Tile Company, Detroit, Mich.

The setting of terra cotta in the plants where porous ware is made is a more simple proposition from the fact that there are no boxes to limit the number that can be nested together.

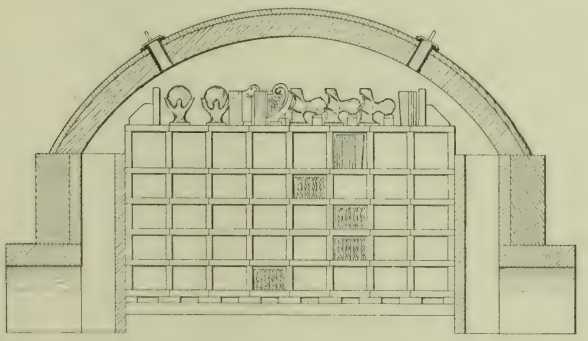

Fig. 168—Drawing of Typical Terra Cotta Setting.

In Figure 169 it will be seen that three courses of loose brick work are set on the floor, then five courses of regular tiles, upon which are placed two layers of cresting. Then, to protect these courses of trimmings, a layer of regular tiles is placed above. Some precaution is taken in this plant to protect the expensive ware, but in many of the plants producing vitrified ware, no shield or protection whatever is given.

In this illustration it will be seen that the tiles start on the floor, no loose brick work being used. *First*, there are three courses of interlocking tiles, then two courses of Spanish tiles, then the special shapes, and finally a course of interlocking tiles to protect them, the latter being placed flat, simply to act as covers.

It will be noted also, that straps have been used between the interlocking and Spanish tiles, and between the Spanish tiles and the trimmings. These straps furnish a better foundation to start upon in changing the setting from one style of tiles to another, and also permit necessary movement between dissimilar surfaces in shrinkage.

SETTING IN SAGGERS.

There yet remains one method of setting that has not been touched upon directly, though the use of rectangular hollow fire-proofing as already described, borders closely upon it.

A sagger is a fire-clay box, or receptacle, made for containing and protecting clay wares in firing. Saggers are naturally of a variety of shapes and sizes, according to the ware they are to contain. They are used most largely in the pottery industry. Nearly all pottery, excepting flower pots and the cheapest grades of stoneware, are saggered. Any other clay ware, which by reason of its light cross-section, is not able to stand the weight in piling to the necessary height in kilns, or which must be protected from flying ashes, dust and soot, or from the burning off of its glaze, or damage to its color by direct impingement of the currents of kiln gases, may be saggered with the same propriety as pottery. Saggers are usually made without lids or covers. Being stacked one above the other in tall piles or "bungs," the bottom of the second forms the cover to the first. At the top of the bung, an empty sagger is usually inverted over the last, as a cover. Sometimes cover slabs are made for the top course.

Only one plant was found in this country which had used the sagger system; viz., the Bennett Roofing Tile Company, of Baltimore, Md. This plant was running in connection with a white ware pottery, and it is not to be wondered at that many of the pottery methods were carried over into the tile plant. Other roofing tile plants in their beginning are known to have used saggers, but none have persisted in it. The great objection to using saggers is the expense. They are quite

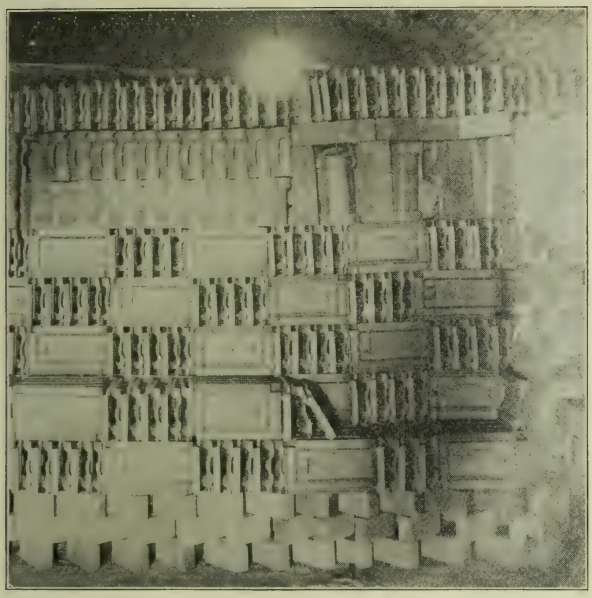

Fig. 169—Setting of Tiles and Terra Cotta, National Roofing Tile Company, Lima, O.

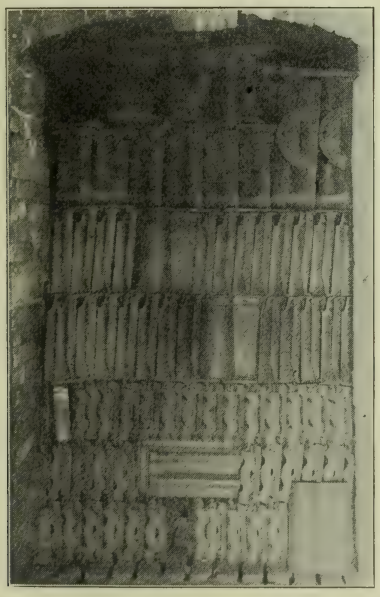

Fig. 170—Doorway Showing Mixed Setting, Mound City Roofing Tile Co., St. Louis, Mo.

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expensive to make; their breakage is very heavy; they do not nest close, and hence use up kiln space rapidly, and they weigh a good deal, and hence consume much heat on each burn.

To make them more durable they are usually made in oval or round shapes, rather than square, as would best suit tiles. With the round saggers much space is lost in the kiln, making the capacity of a kiln very small when compared to the regular setting.

While the use of saggers cannot be advocated for the setting of regular roofing tiles, more can be said in their favor for glazed wares and the subject will be taken up in the chapter on glazes.

SUMMARY.

While very little, if any comparison can be made as to economy, between the two principal systems, the class of ware burnt in one case could not be burned by the other method, and in the other case, it would not pay to use kiln blocks for setting ware that is not to be burned hard.

The proper method to use will depend on which kind of ware the manufacturer wishes to make, vitrified or porous. The clay to be used will very frequently govern the details of setting within the general system. Some clays begin to vitrify so early that they could not be burned except in kiln boxes.

As between kiln blocks and saggers, everything is in favor of the kiln blocks. When drawing a kiln, they can be stacked to the sides of the kiln in a comparatively small space, while the saggers are very bulky and most of them must be removed from the kiln, thus making an additional cost of handling and incidentally more breakage also. The kiln blocks are heavy and strong and resist handling well, while saggers are fragile and of short life at best. Both kiln blocks and saggers materially increase the fuel consumption per ton of finished clay ware produced, and the blocks probably weigh more in proportion to the ware they support.

CHAPTER IX.

KILNS FOR BURNING ROOFING TILES.

The burning of clay wares—or baking as it might more properly be called, since the wares themselves do *not* burn—is the last, most difficult and most critical step in the whole process of manufacture. By it, the solid, but still soft and easily destructible dried ware is converted into a hard, more or less vitreous weather-resisting artificial rock. The process is accomplished by bringing the ware through a series of increasing temperatures, affording time at each stage for the chemical reactions to take place, and finally reaching a point, in vitrified wares at least, where the body is in a state of incipient fusion, and ready at the least strain or least increase in temperature to undergo deformation and loss.

The chemical processes concerned in the burning, and the way that the qualities of the product are affected by and dependent on burning conditions, have been set forth somewhat fully under testing, in Chapter III. The present discussion will deal chiefly, therefore, with the apparatus and methods by which this work is accomplished.

Since clay burning has been going on in all parts of the world since the earliest stages of culture, when man had hardly risen above savagery, and since for some hundreds of years at least, this work has been carried on on a large scale, and as one of the prominent and essential industrial arts, it would seem natural to expect that experience would have eliminated the more crude, inefficient, and uneconomical methods and enabled clay workers to limit their selection of kilns to a comparatively few well proved types. To some small extent this has occurred, but there still remains an astonishing variety of kilns, of old and well known types, and not including those newer phases which have not yet had time to fully win their permanent place, and it is not yet possible to prove beyond mere unsupported opinion which are really economical and which are not.

Beyond question, there are many kilns in existence, whose type is unscientific and whose performance is poor, and yet they are not only still used, but new ones are built. The problem of deciding on what is really good and what is not, is much complicated by several factors—

1st.—The inherent variation in clays. Some clays are fired rapidly and some slowly. Some are very sensitive to the least over-firing,

some stand punishment without much effect. Some require very strict cooling conditions, and some may be chilled recklessly.

2nd.—The variety in the products. Every kiln must be suited to its charge. It would hardly be natural to expect to fire gas retorts weighing tons, and table-ware weighing ounces, in one and the same structure. The form, size, cubic capacity, doors, arrangement of fire holes, etc., will all have to be adjusted with reference to the ware habitually fired.

3rd.—The inherent variation in fuels. Furnaces must naturally be adjusted to fuels, wood, soft coal, hard coal, lignite, coke, oil and gas, but in addition, the kiln chamber will require adjustment, according to the flame length of these various fuels. Some fuels will compel the use of a muffle to protect the ware, while with other fuels a muffle kiln will have to be abandoned in favor of an open type, in order to get the heat distributed safely.

4th.—The unwillingness of clay workers to publish and compare data. Trade secrecy in the past has had a strong control of the clay-working arts. And today the feeling still holds to a very surprising extent. Even if clay workers were anxious to eliminate poor methods, and low grade kilns from their factories, there are enough barriers in the way of making comparisons sufficiently exact to thoroughly prove either for or against many fine points in kiln design. But when manufacturers are unwilling to discuss and compare data, for fear of giving each other a fancied advantage, or of exposing their own lack of knowledge, the problem of weeding out inefficiency becomes mountain high.

Without doubt, other causes in explanation of the status quo might be brought forward, but enough has been said to show why burning is still so little of an exact science.

If the countless variations in kilns which have been or are in existence are studied, and indeed it is rare to find two alike except on the same plant, it will be found that these variations are classifiable to a considerable extent, and that the classes thus made will include large numbers of kilns varying in small or immaterial details, while agreeing in fundamental principles. Such a classification recognizes two main subdivisions, I, periodic or intermittent kilns, II, continuous kilns.

The names indicate the nature of the distinctions. In intermittent kilns a charge of ware is fired to the finishing point, cooled down, discharged, the kilns are reloaded and the same cycle is repeated. In continuous kilns, by movement of either the ware to the fire or the fire to the ware, masses of ware are always being brought to their finishing point, and hence in other parts of the structure, ware is being heated up and cooled down, so that all parts of the burning cycle are going on at once in different portions of the continuous kiln, while in the periodic kiln one thing at a time is done, and so far as possible, the same thing in all parts at once.

PERIODIC OR INTERMITTENT KILNS.

This group is the numerous and commonly represented one. A very large percentage of all ceramic kilns belong in this group. Though admittedly a less scientific and perfect apparatus from the fuel combustion standpoint, they have certain virtues which will always guarantee their use. They are cheap to construct, and therefore require less capital to begin operations. They are rapid and independent of each other. They produce just as good, and in some kinds of ware better products than the continuous.

The intermittent kiln is almost the sole resource in the roofing tile industry of America. In Europe, the situation is reversed, or at least, continuous kilns are vastly more common than here. Intermittent kilns, as found in use in roofing tile plants in the United States, may be classified as follows:

- Intermittent or Periodic Kilns
  - Round ....
    - Chimney Draft.....
      - Single stack
        - Interior (a)
        - Exterior (b
      - Multiple stacks Exterior(c)
    - Mechanical Draft (d)
  - Rectangular
    - Chimney Draft.....
      - Single stacks (e)
      - Multiple stacks (f)
    - Mechanical Draft (g)

There are numerous other types of intermittent kilns, but as none of them are now used in roofing tile plants, or seem to be in any sense an improvement of the kilns now in use, no effort will be made to make this classification more comprehensive.

ROUND KILNS.

A. Round Down Drafts with Interior Stacks.—While there are some very good features in this type, it has been but very little used in this industry. One firm, the United States Roofing Tile Company, is the only one in the United States using it, although it has been quite extensively used in other branches of ceramic manufacture.

A clear conception of this kiln, as used by the above company, can be obtained by reference to the drawings shown on page 919 (Figure 171).

The kiln as built is twenty-four feet inside diameter. The walls consist of a nine-inch fire brick lining, and a thirteen-inch outside wall of common brick. From the floor to the spring of the arch, is seven feet six inches. The crown has a rise of five feet three inches, thus making the total inside height from the floor to the apex of crown, twelve feet and nine inches.

The foundation walls are four feet wide by three feet deep, measuring from the grade line. The "hub," as that portion of the kiln in which the furnaces are constructed is called, is thirty-six inches wide.

By referring to the sections showing the ground plan, the flue system of the kiln can be readily understood. It will be seen that below all other parts of the floor is the large four-way or cross flue; this flue is twenty-four inches wide by thirty inches deep. At the junction of the four-arms, and carried by the side walls to the large flue, is the center stack, which is twenty-four inches in diameter, with four inch walls of circle bricks.

Connecting the four outer ends of the four-way flue is a circular or ring flue, twelve by twelve inches, shown in section D-D. This ring flue intersects the main cross flue, so that their upper surfaces are on the same level. On top of the ring flue is a system of radial flues shown in sections E-E and F-F. The radial flues are sixteen in number, nine by nine inches in cross section, consisting of eight long flues reaching from the stack to the side walls and eight short or intermediate flues that reach from the ring fiue back almost to each bag.

The covering to the radial flues is of stock floor or flue bricks, twelve inches long, part of them having an open slot one by five inches on one side. (See Section FF.)

The space between the radial flues is filled in solid and paved level with the top of the bricks covering the flues. Thus the kiln has a solid floor over about one-sixth of its area. The flue bricks can be taken out at any time in order to clean out the flues; no other part of the floor need be disturbed. The slotted bricks can be shifted about to secure the best distribution of the gas currents.

It will be observed that the bag walls, G, are very low in this kiln. only about two feet above the floor. It has been found by experience that a higher bag throws too much heat to the top of the kiln. With the present bag the heat equalizes very nicely. The firing is done with natural gas.

The small sketch shows the style of furnace used. A two-inch gas line is carried around the kiln on the hub. At each furnace a one-inch drop line is carried down to a point where the blast from the burners will strike just above the floor level. There are two stop-cocks in the drop line, one in the down pipe and the other between the burners, thus one burner can be lighted at a time. The burners are of the ordinary type, having a cast iron mixer, into which short lengths of two-inch pipe are put to form the burner nozzle.

Just above the burner can be seen two openings, five by six inches. When the kiln is first lighted these openings are closed, but as the burn progresses they are opened more and more until wide open at the finish.

The heat generated in the bags passes up into the kiln, is drawn down through the ware into the radial flues, then into the ring-flues, which in turn carry it to the four-way cross-flue, and thence it passes up the stack and out to the open air.

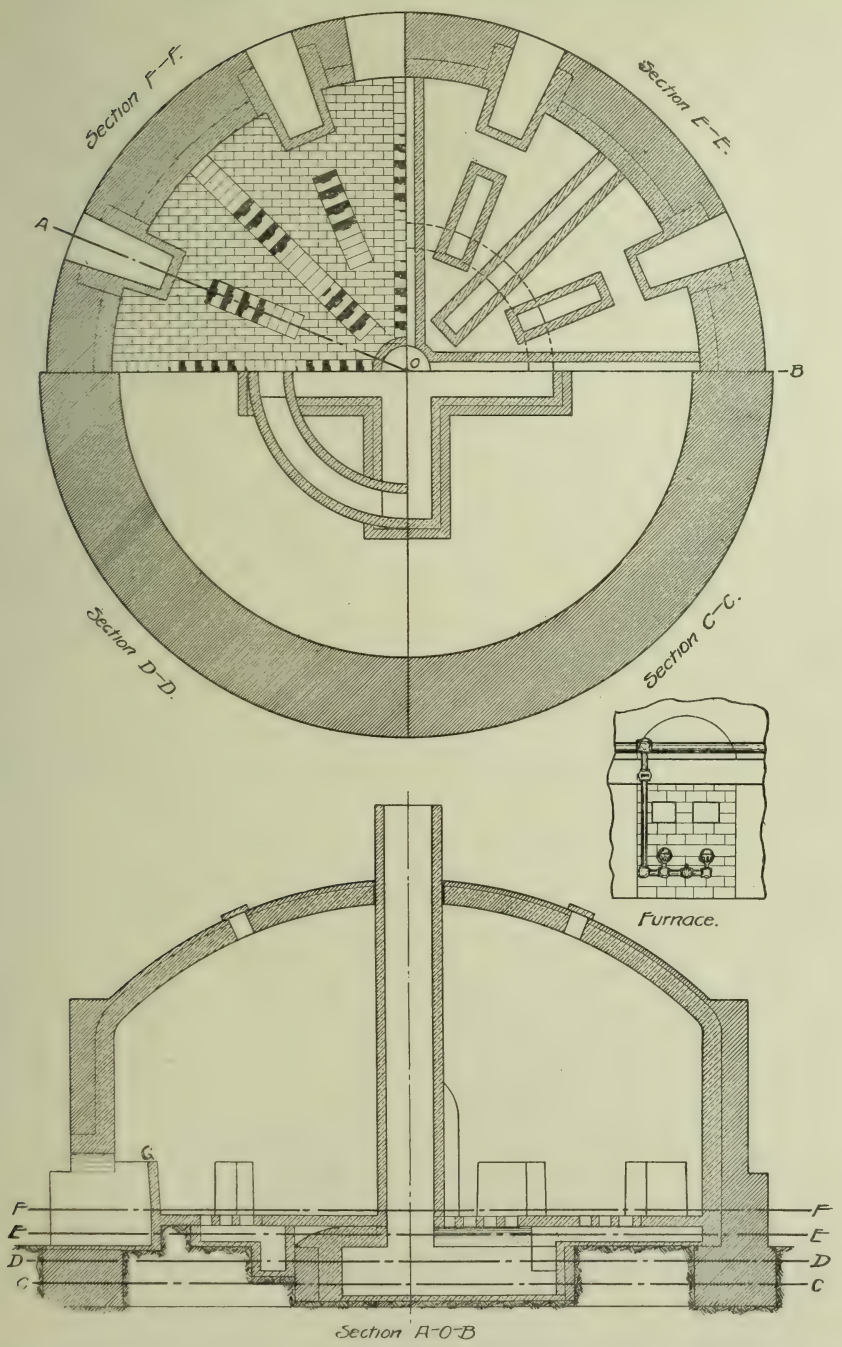

Fig. 171—Center Stack Down Draft Kiln, United States Roofing Tile Company, Parkersburg, W. Va.

In an ordinary burn, lasting from four to five days, about 400,000 cubic feet of gas are consumed.

Advantages of this Kiln.—First: The flue system lends itself very easily to changes found necessary from burn to burn to regulate the distribution of the draft. *Second*: The flue system can be very easily cleaned. All that is necessary to do is to lift out the flue brick, and then with a small fire shovel remove the debris. *Third*: The center stack becomes heated very early in the burn, thereby furnishing a good draft at a time when it is needed to remove the water smoke and prevent the deposition of scum or whitewash. *Fourth*: The fact that all waste heat must pass through the center of the kiln insures that the center will not be materially lower in temperature than other parts. *Fifth*: In comparison with kilns having their stacks outside, it is very much cheaper to build. The center stack is only four inches thick and is very short. There are no underground flues to connect it with the kiln, as in outside stacks.

Disadvantages.—First: The available kiln space is reduced by about twice the cubic contents of the stack each burn. This, however, is not large, rarely over five per cent., and often less. *Second*: The strongest objection is due to the stack being in the way of setting and drawing the kiln. This objection is valid, especially with roofing tiles set in kiln blocks. It becomes very troublesome to work around the stack. Also, the dry ware to be set can only be brought half way in the kiln on a car. With trucks this trouble disappears. If the kiln were built larger it would be possible to get a car of tiles past the stack, but with small kilns it is not.

While the stacks as built by this company have no dampers on them, this type of kiln admits of very easy control by a top damper. It is a much more economical plan to have a damper fitted to the top of each stack than in any other way, and the draft can be kept under control as the heat increases.

B. Round Down Draft Kilns with Exterior Single Stacks.—There are three plants using kilns of this type. One that has been in use for the past ten or twelve years in the plant of the Cincinnati Roofing Tile Company, using coal for the fuel, is shown in the drawing, Figure 172.

The kiln is twenty-two feet in inside diameter, with walls twenty-two inches thick above the hub. The hub has two offsets. The inside height is seven feet to the spring of the crown, with a five foot rise, making twelve feet high at the apex. The bags in this kiln extend up five feet above the floor, differing from the gas-fired kiln previously described. It was found better here to carry the gases from the coal furnaces up into the crown of the kiln, and allow combustion to complete itself at that point and then pass down through the ware. The quality of the fuel is therefore the determining factor in this change.

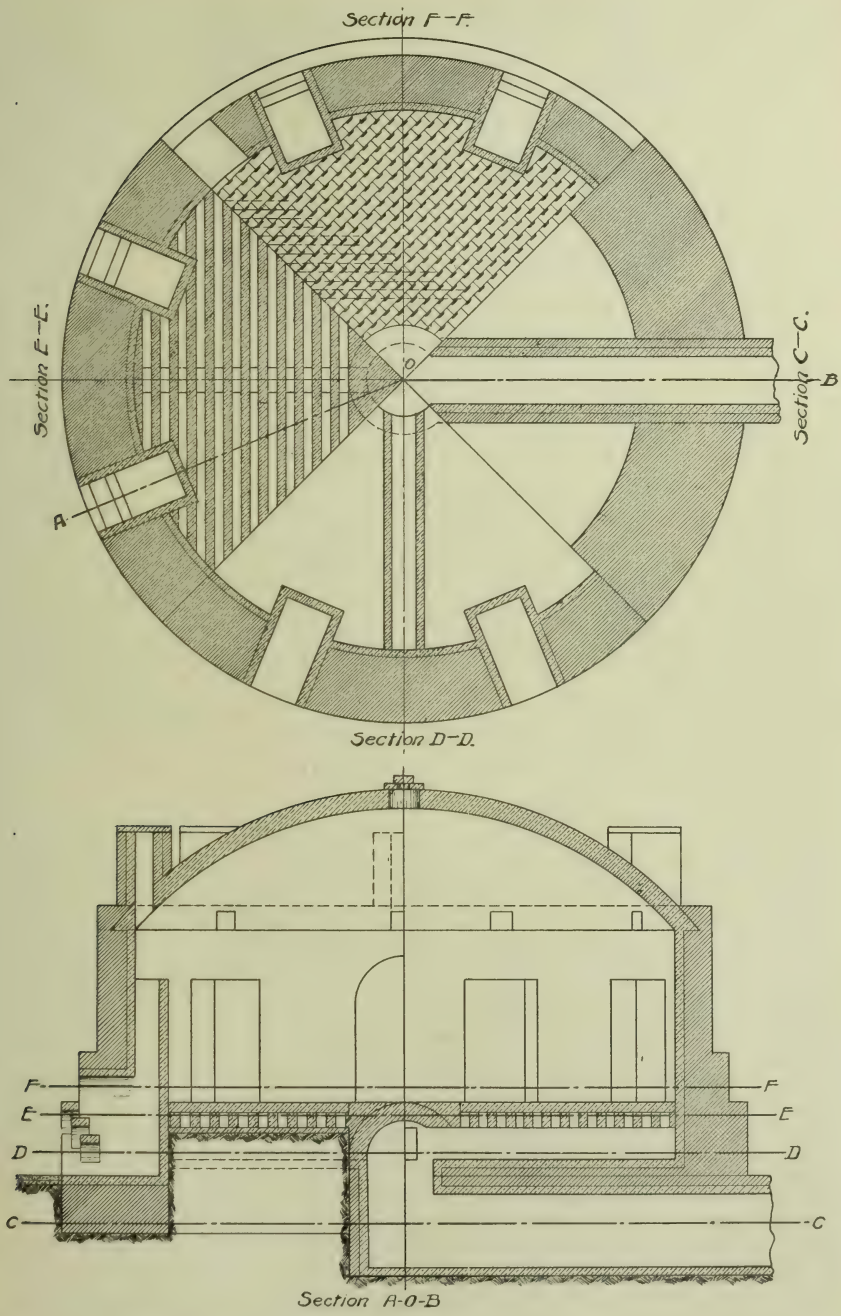

Fig. 172—Round Down Draft Kiln. Cincinnati Roofing Tile & Terra Cotta Co., Cincinnati, O.

The flue system is in part like the kiln just described. In the center of the kiln, and under the floor level, is a well-hole thirty inches in diameter. Leading from the well-hole out under the wall of the kiln to a stack is a large flue, twenty-four by thirty inches. Opening into the top of the well-hole are four cross-flues, twelve by sixteen inches, in cross-section, which lead to the walls of the kiln. Just above, and crossing the four flues at right angles in each quarter of the kiln, are a set of small, narrow flues four by twelve inches. (See Section EE.) Above these narrow flues is another set of cross-flues upon which the open floor bricks, shown in FF, are placed.

The heat, in passing through the kiln, enters the bags, is carried well up into the crown, passes down through the ware, sieves through the floor bricks into the first small flues, then into the lower ones, and is thence conveyed to the four cross-flues, which carry it to the center well hole. From here it passes by the large flue out to the stack. A vertical damper is placed between the kiln and the stack. In the sections marked FF, the floor bricks should be shown in parallel rows, and not staggered, as indicated.

A rather peculiar feature of this kiln, not seen on any other, is the small vent stacks over each furnace bag. These stacks are about three feet high, and nine by nine inches in cross-section. During the most of the burn they are kept covered with slabs, but in the early part or warming-up period they are more or less open, allowing much of the smoke from the coal fuel to pass out. This gain is at the expense of much of the heat which the coal has generated. The idea is not worthy of imitation.

The furnaces of this kiln are also unique, in that step-grates of brick arches are used. No iron grates are employed. The arches are each about five inches lower than the one above, and sit back into the furnace about five inches farther. In firing a furnace of this type, the fire is lit on the floor, under the bottom arch and well back into the bag. As the fire increases, fuel is fed in from above the uppermost arch. Instead of raking out the ashes, they are allowed to fill up, until at last the fuel fills the fire hole completely, drawing its supply of air through the spaces between the arches. The furnace is like an ordinary dead-bottom one, but the arches act as a substitute for the mass of clinker which holds up the fire and lets air get through it. The brick arches, or step-grates, are widely used abroad, but are uncommon in the United States. For some coals, they offer great advantages over the clinker grate. The only disadvantage they offer is in cleaning out the fire hole, either during or after the burn. With a very clinkering coal, this trouble might be rather serious, but with ordinary fuel, it would be unimportant.

This company uses these fire-holes as miniature gas producers. That is, they generate the gas in the fire-box, and complete the com-

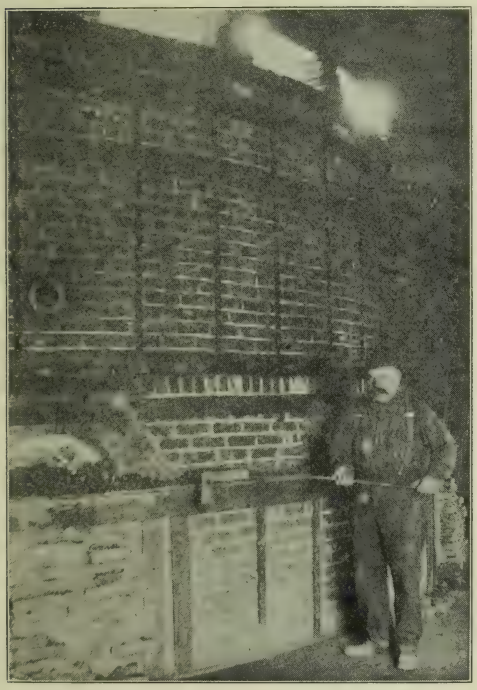

Fig. 173—Gas Producer Furnace Under High Fire, Cincinnati Roofing Tile & Terra Cotta Co., Cincinnati, O.

Fig. 174—Double Furnace Down Draft Kiln, Ludowici-Celadon Co., New Lexington, Ohio.

bustion in the kiln. It will be seen in Figure 173 that the entire lower part of the furnace has been shut up with bricks and kiln blocks. The fuel is piled up until it nearly shuts off the air space under the arch. As the fuel roasts and cokes, it gives off gas which passes up the bag; meeting a supply of air at the inlet-pipe shown above the furnace, the two mix and pass on into the kiln, burning as they go. Complete combustion does not take place until the gases have traveled a considerable distance.

Advantages.—First. The entire flue-system, except the stack-flue, is above grade, thus insuring a dry bottom to the kiln. *Second.* The furnaces are cheaply constructed.

Through long experience with this kiln, it has become possible to obtain very uniform burns, with but a small percentage of loss.

Disadvantages.—First. The flue system is rather expensive to construct. *Second.* The flues are very hard to clean. It is necessary to take up the upper set in order to reach the lower ones. *Third.* The draft is very apt to be stronger over the four cross-flues than elsewhere. No provision has been made to prevent this. *Fourth.* There is no provision made to control or shift the hot gases to various parts of the kiln, other than the manipulation of the fires. *Fifth.* The small stacks are an added expense, and when opened only serve to carry the heat from the bag direct into the air. It would be better not to generate the heat in the first place, if it has to be gotten rid of. *Sixth.* The furnaces are very hard to keep in repair. The small arches are very easily knocked out, while cleaning out ashes and clinkers.

As to the method of firing; viz., working the furnace as a gas producer, if properly handled, it is a very good plan. It puts the combustion of the fuel and the evolution of the heat at a point where needed, and where the greatest benefit can be derived. Another strong point in its favor is that very little ash or dust is carried over into the kiln. The air in passing through the thick fuel-bed creates an intense local temperature, which makes the ashes sticky and there is little tendency for the ash to fly along into the kiln as in flat-grate furnaces. It takes about five days, using the best Pocahontas coal, to fire off a kiln. Depending on the climatic conditions and the kind of ware set, the amount of fuel consumed runs from fifteen to twenty tons per burn. A comparison of fuels used in various plants is of little value, unless all conditions are considered.

The Ludowici-Celadon Company, at its New Lexington, Ohio, plant, uses kilns twenty-six and thirty feet in diameter, and about twelve feet high in the center of the crown inside. Their main difference from the preceding is the construction of the flue system, which is in reality a combination of the two previously described. The gases are all collected in a center well-hole, and sent to the stack by a flue leading out under the kiln wall. Leading into the well-hole are

radial flues, which reach out to the outside wall between the bags. About midway between the well-hole and the wall is a ring flue, intersecting all of the radial flues. From the ring flue, shorter radial flues are led off between long ones, and terminating at the point of the bags. Thus the kiln bottom is well served with radial flues. On top of the radial flues is a zone about eighteen inches high, traversed by parallel cross-walls, supporting the paving course or floor proper. These walls are built with spaces between each brick, as open as consistent with stability. The common name for this is "feather work" or "mid-feathers." The purpose of the "mid-feathers" is to permit the gases which have passed the floor to flow laterally in any direction to the point of escape with the least resistance. The clogging of one avenue leaves many others available in kilns in which this mid-feather construction is used. The mid-feather, however, is not a mode of forcing the gases to flow to definite points or to insure distribution in passing through the floor. It has no such function, but in many kilns it has been used as if it had. With no means of controlling the distribution of the draft except the "checker-bottom" and "mid-feathers," the worst sort of distribution is likely to result.

There were two sets of furnaces on these kilns, one set using coal and the other natural gas. The kilns were heated up with coal and finished off with gas; the reason being that gas was more expensive than coal. The gas, being less apt to flash the ware than coal, was used to finish the burn, rather than start it.

It will be observed (Figure 174) that there is a large three-inch gas line around the kiln. From this line, one-inch lines pass down to the furnaces, which have been built in between the regular coal furnaces, which are shown closed up with kiln blocks. Since the above notes were taken, the company has been enabled to obtain a greater supply of gas, and has discontinued the use of coal.

Advantages.—First. The flue system is largely above ground, insuring dry bottoms. *Second.* The radial flue system, covered by mid-feathers, allows the heat to move freely under the floor, and thus to equalize. *Third.* The floor or flue bricks, being easily movable, enable the draft openings to be rearranged, by inserting solid bricks in place of perforated ones. They also facilitate the work of cleaning the bottoms.

Disadvantages.—It has a weak draft in the early part of the burn. This is typical of all kilns having deep bottoms and outside stack connections. They also are subject to weather changes. As a whole, it can be said that these were the best round kilns found in use.

One other plant was visited in which round kilns with outside stacks were used. The kilns in this instance were of twenty-six feet inside diameter, and of the usual height. The exact arrangement of flue system in the bottom could not be obtained. It was much too

deep-seated; that is, the floor was at grade-line and the flue system was all below grade, and certainly would be likely to be very damp. The tiles that were being produced in this plant had all the indications that such was the case, for they were not only soft burned in the lower part of the kiln, but were very badly scummed.

C. Round Kilns with Multiple Self-contained Stacks.—There was only one plant using this style of kiln. In this instance, the kilns were of two sizes, twenty-four feet and twenty-eight feet in diameter inside, and having a central inside height of about twelve feet. The bags were about thirty inches high above the floor. The floor itself was nearly solid, except for openings five inches by five inches, about twenty-four inches apart, along radial lines from the center of the kiln to the walls. These openings led into flues running from the base of small stacks, located in the kiln-wall between each fire place, toward the center of the kiln. These flues did not meet in the center, or elsewhere. They were about twelve inches by twelve inches, inside dimensions. The stacks were carried independently above the side walls of the kiln about six or eight feet.

In theory, the multiple stack appears good, but the actual operation is otherwise. The idea is that each stack will drain one section of the kiln floor, and that by regulation part of the floor can be brought up or held back at the will of the operator by merely using a damper.

In practice it is found that in order to drive the heat to any one or two sections of the kiln it would be necessary to shut all the other sections off, and in doing so the draft would not be sufficient to maintain oxidizing conditions.

The building of the stacks in the wall of the kiln is a source of weakness to the walls. The stacks become hotter than the adjoining parts of the wall, and hence expand more, bringing about a continual strain, which in time will rack and materially weaken them.

The above described multiple-stack kilns are using natural gas. The burners are of a patented type, known as the Kearns Automatic Gas Burner. The burning is of three to four days' duration, and consumes from 140,000 to 160,000 cubic feet of gas.

Advantages.—First. It is claimed that the draft can be localized to any particular part of the kiln. *Second.* No yard room is taken up by the stacks. *Third.* They are cheaper to construct than outside stacks, being shorter. *Fourth.* The kiln has no deep flue system, as the stack openings may be on a level with the floor if desired.

Disadvantages.—First. The draft control is not nearly as exact or satisfactory as the projector of the idea expected, as explained above. *Second.* In starting off the burn, the stack areas are in excess of the kiln needs, and reversion of the draft is very common; i. e., a stack will suck cold air into the kiln instead of carrying hot gases out. This is difficult to prevent, and takes a great amount of care and watching.

D. Round Kilns with Mechanical Draft.—At no point were kilns of this variety being used, but this system could very well be applied to many of the round kilns now in use, which now have a sluggish draft and are giving poor results at high fuel cost. The system will be discussed in connection with rectangular kilns.

Summary on Round Kilns.—It can safely be said that the use of the round kiln in the roofing tile industry has passed its climax, and is rapidly being replaced by the rectangular kiln.

While the round kiln can be built cheaper, and has a longer life, it has drawbacks that more than outweigh these advantages. The great objection for roofing tile purposes is that they interfere so seriously with convenience in setting. The curved walls do not lend themselves readily to the system of setting necessary. It is impossible to brace the stands at the side walls in the proper manner. Too much valuable space is lost by having to insert so many side braces in the tile benches. Also, the individual fire-bags or "pockets" around which the ware has to be built interfere seriously. A circular flash wall is possible and is undoubtedly better, but is seldom used, on account of difficulty in keeping it up.

A much greater per cent. of flashed ware is obtained in round kilns than in the rectangular. This is due to the fact that about one-half of the fire-bags are throwing their hot gases into the kiln at right angles to the benches, that is, against the sides of the tiles, while in the rectangular kiln all hot gases come into the kiln parallel with the benches.

It cannot be denied that excellent results can be obtained with the round kiln. It has an unquestionable advantage in the ease with which a flue system can be made to give even draft over the whole floor.

Fuel consumption is less in the round kiln than in a rectangular kiln of the same superficial floor area, owing to a proportionately less wall area. This difference is probably offset by the less lost space in the rectangular kiln, by which the heat that is generated is made to do more work.

But notwithstanding all the good qualities of the round kiln, it is on the average impossible to turn out ware as cheaply as in the square kiln, or of as good quality and quantity.

If built at all for burning roofing tiles, the round kiln should be large, about thirty feet in diameter, so that the loss in setting will be reduced to a small factor. The height of the kiln should also be greatly reduced from that in general use at the present time (twelve feet). It would be better to build eight feet, and at the outside figure nine feet in height at the center of the crown. The kilns built in the past are so high that it is extremely hard to get the heat to the bottom.

Very frequently the top ware is overfired in the effort to bring up the bottom temperature. With a lower crown this would be largely overcome.

As to the flue system, it should be of the radial type, leading to a central well-hole. The floor should be as near solid as possible, on account of the large amount of scrap that will otherwise fill up the flues. The so-called checker floor is not recommended.

The chimney, if one is used, should be outside of the kiln. One large stack for four kilns is satisfactory. Mechanical draft should be used where possible.

The furnaces of course will depend on the nature of the fuel. If coal, either the flat or inclined grate-bar type is preferred. While the flat grate-bar furnace will require more labor and attention, it will, if properly attended to, give the best results, and use the least fuel. The main trouble with the flat grate-bar furnace is, that the bed of fuel, if kept thin, burns through in patches every few moments, thus allowing streams of cold air to enter the kiln. If the fuel layer is not kept thin, all the advantages which belong to the flat grate type are lost, and one might as well use the inclined or dead bottom types at once. The inclined grate-bar furnace, on the other hand, is more likely to prove better in the hands of a careless burner, because the fuel layer will slide down the bars, and automatically prevent leakages of air to a large extent, and thus does not require such constant attention.

RECTANGULAR KILNS.

This style of kilns is at the present time most popular among the roofing tile manufacturers, and is likely to remain so. There are at present over half of the plants using rectangular kilns; those rebuilding or putting in new kilns at the present time are all installing the rectangular kilns. This tends to show where the general opinion rests, and it has not come from the desire to try something new, but as the result of actual experience with both types of kilns in many different plants.

The general objections to rectangular kilns are: First, that they are more expensive to build and keep in repair than the round kilns; second, that it is more difficult to get an even distribution of the draft over all parts of the kiln, the ends and corners of the kiln being the most difficult to bring up uniform with the rest. Both of these objections are real, but are overbalanced by the advantages.

E. Rectangular Kilns with Single Exterior Stacks.—Two plants were visited in which kilns of this type were in use. The kilns themselves were very closely like that of the Detroit Roofing Tile Company, which differ only in the use of mechanical or fan draft instead of a stack, and the description and drawings will be given under that heading (G.).

The points in favor of a single stack vs. multiple stacks are much less pronounced in rectangular kilns than in round ones. If rectangular kilns were square, it would probably be better to use one stack per kiln, as in round kilns, and for the same reasons. But as nearly all rectangular kilns are not square, but much lengthened on one axis (in one instance three hundred feet long by only eighteen feet wide), the problem of securing uniform draft distribution over the whole floor surface is much altered.

In general, the advantages which accrue to one stack for a circular or a square kiln can be retained in long rectangular kilns by making the kiln's length equal to two, three or more times the width, and dividing the floor by cross walls into squares, each of which has a stack and a complete flue system of its own. For instance, with a kiln eighteen feet wide the length might be made thirty-six feet, and two stacks used, or fifty-four feet and three stacks, or seventy-two feet and four stacks, etc. The kiln thus becomes in effect a series of contiguous square kilns in line, surrounded by exterior walls and roof in common. The general principles found useful in round kilns obtain with rectangular kilns, also, viz., floors above grade level, shallow flue systems to avoid dampness and excessive fuel consumption, exterior stacks to save loss of interior space, a flue system extending to all parts of the floor with equal frictional surface, solid floors covering the flue system, perforated to admit the gases so as to give to every square yard of floor area an equal draft, a stack adequate to give a good draft in the beginning of the burn, when the temperature is low, and damper arrangements which will give entire control of the draft at any stage.

F. Rectangular Kilns with Multiple Stacks.—By this is meant the use of stacks in more frequent proportion than one per "unit square of floor space" (i. e., a length of space equal to the width of the floor). Multiple stack kilns use from two to five times as many stacks as are recommended in the "unit floor space" plan.

The Eudaly Type.—The type of the multiple stack kiln is the Eudaly, originally introduced as a patented kiln, and sold extensively over the country on the yard-right plan. For years the essential features have been pirated in so many ways that many kilns can now be found which are Eudaly in type, but not in details, and built without authority from the owner of the original patents. This even took place while the original patents were still comparatively new.

A kiln of the Eudaly type is in use at the Huntington Roofing Tile Company's plant, Huntington, W. Va. It is eighteen feet wide by thirty-eight feet long inside, by seven feet to the spring of the crown. The crown has a rise of five feet, making the total height twelve feet. The floor system is the characteristic feature. The rectangular bottom is divided by a center wall extending lengthwise of the kiln bottom from

end to end. At right angles to this dividing wall are cross walls, spaced opposite each furnace, and extending from the kiln wall to and connecting with the center wall. Thus the kiln bottom is divided up into sections, each of which has its own flue system, connecting with its own chimney in the side of the kiln wall, midway between each furnace. These blocks are usually about seven or eight feet wide by eight to ten feet long. The area of the stack draining this area is small, about twelve by eighteen inches.

These stacks connect with flues running straight through the middle of each section to the center wall. The bottom of the stack and the flue are on the same level, generally about thirty-six inches below the floor line. The flue is about eighteen inches deep. The whole section, seven feet wide by eight feet long, is now covered with small four-inch mid-feather walls parallel to the axis of the kiln and five inches apart. These mid-feather walls cross the flue in the center by arching, or by tiles on edge, or even lapping each course till one brick will bridge the gap. The mid-feather walls are now covered with perforated floor brick. This makes a floor through which the gases pass with perfect freedom at any place, and therein lies the vital defect of the system.

The claims made for the Eudaly kiln were that by having each section of the floor drained by a stack of its own, perfect control of the draft was assured, it being only necessary to operate the dampers on the stacks to force the draft to any particular section of the kiln. This idea appears plausible, but in actual practice it does not work out as expected. The hot gases, being able to pass the floor at any point, will take the shortest road to the stack. The central area of the kiln, furthest from the stacks, and the floor along the cross-walls are practically without draft. There is another trouble, viz., the stack area is extravagantly great. The result of this great stack area and the open or "checker" floor is that the gases supplied to the kilns by the fire boxes rush to the base of the stacks by the "short cut," and leave the more distant parts of each floor section stagnant.

Closing a damper on one stack does no good. Unless practically two-thirds or three-fourths of the dampers are closed, no compulsion is exerted on the draft movement, for the excess of stack area is so great. The cross-walls in the bottom are absolutely ineffective as a mode of control of the draft distribution. There are also too many dampers to regulate. Too much of the burner's time will be consumed for the results obtained.

Ordinarily the Eudaly kiln is fired with coal, but in this instance gas is used. The time of firing is extremely slow, about twelve to fifteen days being spent for the entire burn. It must be remembered that the Huntington Company is manufacturing flat shingle tiles exclusively, and this style of ware and the method of setting at this plant require a long, slow burn to get proper results.

A bad feature of this kiln, as constructed in the above plant, is the height. It is from three to four feet too high. The top area becomes excessively hot and by its radiations down onto the ware there is constant danger of spoiling the top courses. With a low crown filled full of ware, the gases would flow among the ware and heat it much more evenly.

Stewart Kiln.—The National Roofing Tile Company were using Stewart kilns, the inside dimensions of which are fourteen feet wide by twenty-five feet long. They are six and one-half feet high to the spring of the arch, with a three foot rise, giving a kiln of nine and one-half feet in total height, which seems an excellent proportion. Their novel feature is the method of bringing the heat into the kiln, and out again.

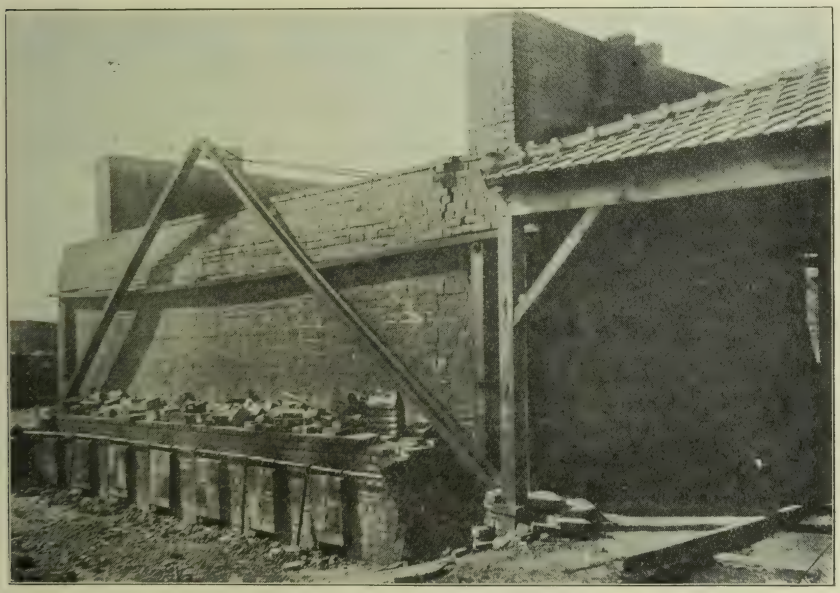

Fig. 175—Stewart Kiln, National Roofing Tile Co., Lima, O.

Along each side of the kiln are flat-grate furnaces, of which the flues lead under the kiln floor to the opposite side, where they deliver the gases up into ordinary fire bags. The furnaces on the right hand side of the kiln furnish the heat for bags on the left hand side, and vice versa. These flues passing under the floor become intensely heated, and transmit a great deal of heat upwards by conduction through the floor, and radiate it among the wares piled above. The gases entering the kiln at the tops of the bags heat the ware from the top downwards. The zone of least temperature is between these two sources of heat, usually about one-fourth of the way between the floor and the top of the setting.

The construction of the flues and the floors requires more care than usual, because they carry the greatest weight and the highest tempera-

ture. Any softening or failure means great loss. The thickness of the floor varies from nine to four and one-half inches in different cases, depending on the wares to be fired. The less sensitive the ware, the thinner the floor may be made.

The gases are then taken out of the kiln at the floor level by stacks opening into the kiln walls. No floor system of any sort for regulating the distribution of the draft is used. This is the weakest point in the Stewart kiln, and has been much improved at the plant of the Columbus Brick and Terra Cotta Company, Union Furnace, Ohio, by bringing in a flue system which is not a part of the Stewart system.

Advantages—First, the main claim for this kiln by its makers is that it is possible to burn the bottom as hard as the top; second, that the bottom of the kiln warms up first so that the ware in the lower half of the kiln does not sweat in the early part of the burn and become kiln marked or scummed by dampness; third, the solid floor makes cleaning very easy and the draft is always unobstructed.

Disadvantages—First, the distribution of draft is very poor. Instead of passing down through the ware to the floor at all points in the kiln equally, it tends to pass over the top of the ware, and down near the end where the outlet flues are located. Thus a large part of the central area of the kiln must be heated by conduction and secondary convection, and not by direct flow of hot gases; second, the loss of heat due to radiation downward into the ground from the flues under the floor is not to be overlooked; third, where necessary to reach a high temperature in the ware, it will be found that the throat to the underground flues will burn out, owing to the heavy fire that must be maintained in the furnaces, in order to carry it under the floor and up the opposite side. This kiln as a whole cannot be recommended, unless its flue system for discharge of gases be materially altered. Even then its fuel consumption is probably pretty high per ton of ware.

Grath Solid Bottom Kilns.—This kiln was found in use at the Western Roofing Tile Company, Coffeyville, Kan. It is fourteen and one-half feet wide by forty-two feet long and nine feet high inside. It has eight gas fired furnaces on each side.

The main difference between this kiln and the one last described is, that part of the heat is carried through under the floor and a part of it can be taken up direct into a bag on the same side where generated. In this respect the kiln is superior to the Stewart, because the furnaces do not have to be forced so hard to get the temperature in the kiln. The amount of heat that need be taken up direct, and not passed under the floor, is regulated by a sliding damper at each furnace.

After the hot gases have entered the kiln, either by one route or another, they are supposed to travel down through the ware and along the floor to the end walls, where they enter openings leading to two

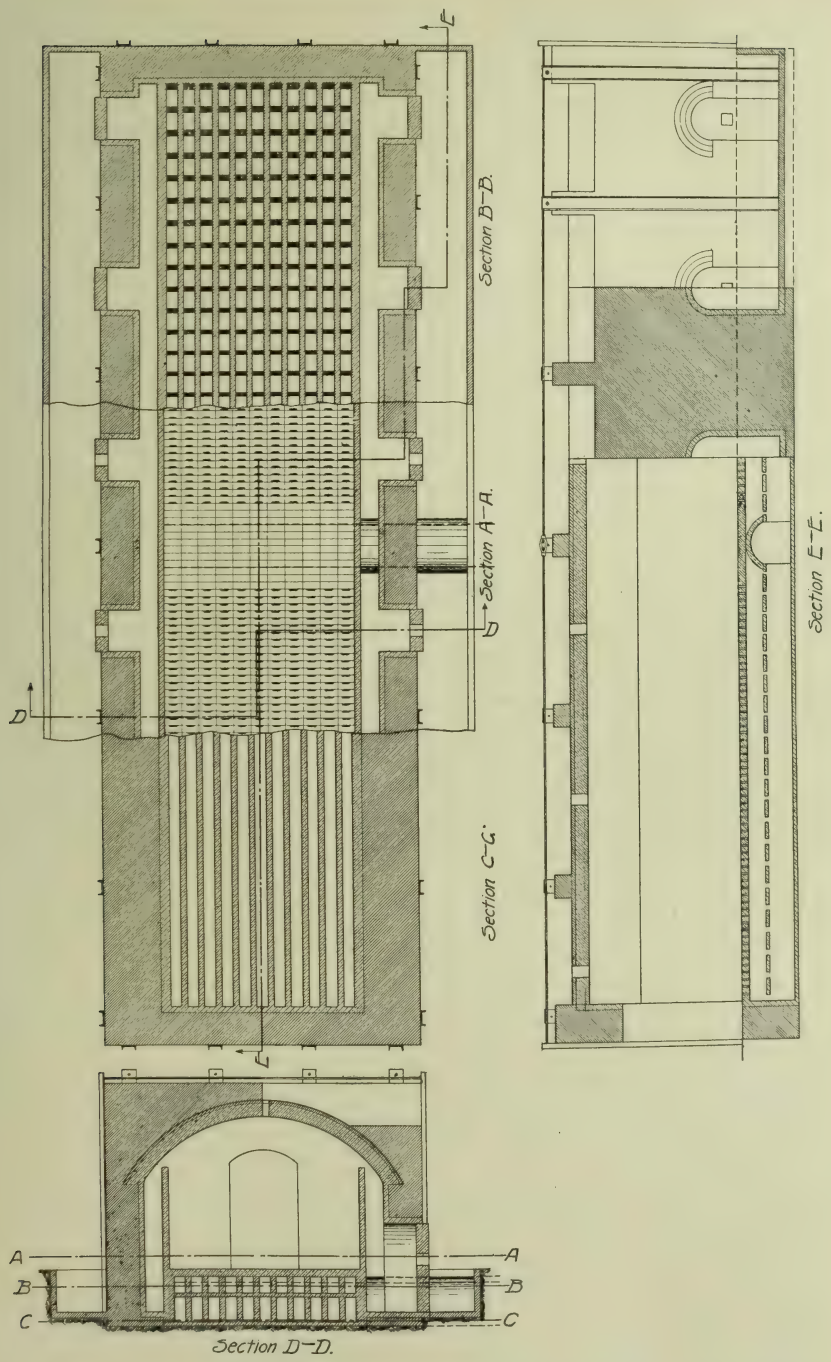

Fig. 176—Mitchell Kiln in Use at Detroit Roofing Tile Co., Detroit, Mich.

small stacks at either end of the kiln. The same objections hold here as for the Stewart kiln, namely, too much radiation loss from the under floor flues, and a very poor draft distribution.

Hence, for economical reasons and uniformity of burns, this kiln is not to be recommended, though it should be given preference over the one last described. It is susceptible of improvement by use of proper flue systems to collect and carry out the gases.

G. Rectangular Kilns with Mechanical Draft.—The Detroit Roofing Tile Company is operating a kiln in a way which may be instructive to others. The drawings of the kiln are shown on page 933. The kiln is fourteen feet wide by fifty-six feet long inside, with a height of ten feet. The walls are twenty-seven inches thick, including the four inch fire brick lining.

The furnaces are now fired with crude oil, but are made large enough, so that grate bars can be inserted, and resort be made to coal at any time. The bag walls are continuous, extending the entire length of the kiln on either side, so that there are no odd corners in the setting. In this kiln it will be observed from the end section D–D that the bag walls are carried well up to the crown; in fact, a four-inch space is all that is left open. Hence, the greater part of the hot gases are thrown well up into the crown of the kiln, before turning down among the ware. The flue system, however, is the important part of the kiln. It consists, first, of a large flue crosswise of the kiln at the center, leading to the fan, which furnishes mechanical draft. Leading out towards the end of the kiln from the cross flue are smaller flues (see section E–E). These flues are about eight inches by sixteen inches, and are covered with kiln blocks, so spaced apart over each flue that openings about two inches wide are left near the center of the kiln close to the main flue. These openings are made larger and larger until at the ends of the kiln they are from four to five inches wide (see Sections E–E and B–B).

After this sub-floor of blocks has been constructed, the mid-feather flue walls are carried up about twelve inches more (see Section D–D). On the top of these mid-feather walls, are placed the open floor bricks or "checkers" (see Section A–A). Immediately over the main cross-flue, the floor is made solid for about five feet wide (see Sections A–A and E–E).

The idea in having the sub-openings through the floors into the flues made larger near the end walls and closer at the center is to equalize the draft distribution, which is always likely to concentrate at the opening into the main draft flue. In this case, the tendency would be to leave the ends and corners cold, and the center hot, if the floor were not built as described. The fact that the floor bricks are laid dry enable them to be moved or shifted at will, and the draft to be changed by inserting solid bricks in place of perforated bricks at any point in the floor where

the draft may have been too great. After the kiln floor is once properly adjusted to suit the local conditions, it will very rarely need to be changed or moved except to clean out the flues. The flues are easily cleaned out; nearly all of the dirt falls upon the kiln blocks separating the upper and lower flues. Hence all that is necessary is to take up the floor bricks and remove the accumulations of scrap and dust. It is not an expensive kiln to build; while the flue system is rather deep, it is of straight brick work, very little chipping or cutting being necessary.

Fig. 177—Outside View of Mitchell Kiln, Detroit Roofing Tile Co., Detroit, Mich.

This kiln as constructed at the above plant is too low in the ground. It will be observed from the drawing that the floor is on a level with the yard grade. The flues are therefore all below grade. In a dry soil this would not be a matter of great importance, but very few localities are so dry that the lower flues are not quite apt to be damp.

In case of coal firing, this question of level of kiln floor to yard level would be very troublesome. It will be noted that the ash pit and furnaces are below grade. Of course, as long as oil or gas is the fuel, this point does not matter.

In Figure 177, the depressed furnaces can be seen, with the oil and steam pipes on the grade line.

The system of staying the kiln is very poor. The large channel irons which serve as buck-staves have been placed on the flat, against the kiln. A channel iron on the flat is very weak. The same amount of iron as has been used in the large channel, if distributed between

two smaller ones placed on edge and using the same tie rods, would support the kiln very much better and the life of the kiln would be greatly prolonged. The proper staying of a rectangular kiln is of vital importance to its durability.

The time of burning this kiln at Detroit is rather remarkable, being about thirty hours from the time of lighting. The temperature is carried to Seger cone 06. Rarely does the time exceed thirty-five hours.

There are several reasons for this very short time of burning: *First*, the clay will stand rapid firing; *second*, the fuel used permits steady firing with no time lost for cleaning fires, the oil being vaporized by steam; *third*, the excellent draft in the kiln, maintained by a fan. The same conditions could no doubt be obtained with natural draft, but it would have to be very strong, and a tall stack would be needed.

Mound City Kiln.—A kiln is being used at the Mound City Roofing Tile Company at St. Louis, which differs from any other in use in the country. It was designed as a continuous kiln, but owing to failure to get satisfactory results from it, its continuous features have been abandoned and the kiln is now used as a compound periodic. It greatly resembles the Dunnachie continuous kiln which was erected in two or three places in this country about twenty years ago, and which also failed as a continuous kiln and was ultimately used as a set of independent units. The Mound City kiln is built in block form, consisting of a double row of chambers four to a row, or eight chambers in all. Each chamber is approximately fifteen feet wide and eighteen feet long. It is fired by four flat grate furnaces, two on either end of each chamber. The two rows of chambers are placed about twenty-five feet apart, so that there is ample room for firing between the rows. Doors are placed at each end of the chambers so that the setting can be done from one side and the drawing from the other.

As originally designed, the heat from a burning chamber was to be carried forward through the next chamber ahead, and then out into the main draft flue. The furnaces are built into the walls as in ordinary down-draft kilns. The heat generated in the furnaces is conducted well up into the chamber by high bag walls. After passing down through the ware, it reaches the floor, which is covered with regular open floor bricks. These floor bricks cover lateral floors extending from end to end of each chamber, and at the center connecting with a larger cross-flue. This latter flue in turn has a "T" connection to the main draft flue leading to the stack or fan. In the case of the Mound City Roofing Tile Company a mechanical draft fan is used.

The kiln to be operated on the continuous plan should be so designed that the heat from the first chamber would pass down through the floor as usual, and then by flues should be carried forward and enter the bags of the second chamber. It would then pass through the ware of chamber 2, and out to the draft fan at once; or, if conditions permitted,

it should be carried through the third chamber as well. Upon reaching the end chamber of one row, the heat should be carried across the intervening space by a connecting flue, and enter the bags of the opposite chamber on the other row.

Advantages.—First. Only a small yard space is required, the chambers being arranged in the most compact form. *Second.* The kiln is cheaper to construct than an equal number of individual kilns on account of saving one wall for each chamber except the first; also, the cost of building a shed over the kiln is greatly reduced, on account of its compactness. *Third.* It can be built in any size to begin with, and then can be extended by the additions of new chambers as occasion demands, without any interference with the original chambers.

This kiln could easily be so arranged that it could either be operated in separate periodic units, or for most of the time as a partially continuous kiln.

For some reasons the continuous kiln proper is more desirable than the above, but for the average roofing tile plant, making a large variety of ware and possibly not operating continuously, the latter is to be preferred. One chamber can be operated at a time, or all at once, to suit the output. With the true continuous kiln the amount of ware set and drawn each day must be very closely regulated. While the fuel consumption in the partially continuous kiln will, of course, be greater than in the regular continuous kilns, this does not offset the conveniences above pointed out. It is so much more economical than ordinary periodic kilns that its use should be attractive in many quarters.

CONTINUOUS KILNS.

In the ordinary periodic kiln the waste of fuel is prodigious. The gases passing out of the kiln are discharged into the atmosphere at a temperature but little below that of the ware itself, and their heat is lost. The kiln, on reaching its finishing point, contains a great quantity of heat stored up in the wares, its walls, roof and floors and fire-places. This, also, is commonly thrown into the atmosphere and wasted. In recent years a part of the waste heat of cooling is often utilized for drying purposes, but under the best conditions there is still a heavy heat loss in cooling.

The continuous kiln in its fundamental form seeks to obviate these two sources of heat loss—first, by using the hot products of combustion through chamber after chamber until they become so cold as to be useless; second, by using the heat of cooling chambers to pre-heat the air currents passing into the kiln, so that the amount of fuel needed to raise the temperature of these currents to the highest temperature required in the burning of the clay wares is only a small amount. No more thoroughly economical device than the continuous kiln for ac-

complishing a thermal reaction on a large scale is to be found in the field of metallurgical or ceramic engineering.

Only one plant in America is using a continuous kiln exclusively for the burning of roofing tile, viz., The Ludowici-Celadon Company, at Chicago Heights, Ill. It has had a continuous kiln for several years. The Alfred Clay Company, Alfred, N. Y., also has a continuous kiln, but is using it more for the burning of pressed bricks than for roofing tiles. The latter are nested in among the bricks when burnt in this kiln.

A true continuous kiln is constructed in ring form, or at least a closed loop of some sort. It may be circular, oval, oblong or square, and even have parallel chambers connected across the adjacent ends to establish the circuit. It may be a continuous tunnel, or a row of compartments separated by cross-walls and connected by flues. The cross section of the tunnel or compartment may be as little as eight feet by ten feet, or as much as twelve feet by forty feet. Where the chamber form is used, the arches may be turned lengthwise or crosswise—the latter is usual. It is necessary to construct very thick buttresses at the end walls or side walls to hold the strain of the arches, or else other means of bracing. Where the kiln is one continuous chamber the arch is continuous with the kiln chamber. In this case it is better to brace the entire side wall of the kiln very strongly with "I" beams and cross tie-rods in order to carry the side thrust.

The kiln at Chicago Heights is a considerably modified Hoffman kiln. The firing is done entirely from the top of the kiln, through small fuel holes spaced equally over the top of the chamber, about four feet apart. Directly under each of these fuel holes it is usual to build a kind of chimney of checker brick work, from bottom to top, so that the fuel, which in these instances is fine coal, when fed into the firing hole, rattles down through the checker work, lodging as it goes and burning where it lodges.

In these kilns the tunnel is not cut up into lengths by cross-walls, or even dropped arches in the roof to mark off the length of the chambers. Hence it is usual to consider the distance from door to door as a chamber. The doors usually open through the kiln walls at about twenty foot intervals.

It is usual in operating a kiln of this kind to set one or two chambers each day. At the end of each chamber it is necessary to form some sort of draft regulator. For this purpose a temporary partition is made of light strips of wood, upon which a cheap and rather heavy paper is fastened in place, often daubing the joints with soft clay. This partition must close the entire cross-section of the kiln. When the paper partition is in place, the setting begins again until the proper distance is reached for a second paper partition, which is then put up, and thus the setting goes on.

In the side wall or floor of the kilns, short connecting flues open into the principal duct leading to the stack, or fan when one is used. This duct may be below the floor, or in either side wall, or even in the roof of the kiln, but the commonest construction is to make the main tunnel in two parallel sections, connected across the ends by smaller flues, and arranging the draft duct between the two tunnels, so that connection with it can be made freely from either side. These connections between the tunnels and the draft duct are provided with valves, or slide dampers, by which the connection can be opened, or shut, or regulated.

When the gases from the fire have traveled through the tunnel to the point where they become cooled down nearly to their dew point, the valve in one of the connecting ducts is opened, and they are carried off through the main draft duct. The paper partitions burn away when the heat gets sufficient, and as each partition disappears the draft valve next ahead of it is opened to carry the gases into the new chamber just connected.

The length of tunnel under operation at once varies, but usually is the equivalent of seven, eight or nine chamber lengths, or from one hundred and forty to two hundred feet. In some kilns this may be shortened down somewhat, but less than one hundred and forty feet is apt to mean that the fullest heat economy is not being attained. The number of chambers ahead (i. e., in the direction the draft is going) of the firing chamber is usually four or five. Three is too few and rarely can the gases be passed through more than five chambers, or an equivalent length of straight tunnel, without being chilled to their dew point, beyond which it is not feasible to use them without heavy damages from staining, scumming, efflorescences, kiln marking, etc. The number of chambers (or equivalent length of tunnel) behind the firing chamber is usually three to five, the number depending on the temperature of the incoming air.

The air passing through the cooling wares can usually be brought to a temperature of 900° to 1000° C., before any fuel is used in heating it to a higher point in the firing chamber. The gases passing from the firing chamber usually drop in temperature from the finishing point to about 900° to 1000° C. in the first chamber, 600° to 700° in the second, 300° to 400° in the third, 100° to 200° in the fourth, and 50° to 125° in the fifth.

The fuel used is from one-fifth to one-third of the amount used in an ordinary periodic kiln of good construction. One quarter represents the average amount.

In the foreign countries where fuel is very expensive, the continuous kiln now has the most frequent use. All classes of ware, from the most common brick to porcelain, are burned in continuous kilns. It was stated by one of the firms mentioned above that their continuous

kiln was carried through a month's burning on a single car load of slack coal, weighing about thirty-five tons. However, this figure would vary widely with the necessary temperature to be obtained, the weight of the wares to be heated, etc.

The greatest objection to the continuous tunnel kiln is the lack of control over the course of the draft. The natural tendency of heated air is to rise, and as the draft in the kiln is necessarily horizontal, the gases are sure to tend to flow along the top or crown of the kiln, overburning the ware at the level and underfiring the lower portion of the setting.

Another trouble, often serious for the manufacturer, occurs in the tunnel kilns. The usual mode of firing is by dropping the fine coal or "slack" through holes in the roof, through the vertical checker-work flues before mentioned. The rapid combustion of the coal in small pieces, especially at temperatures below the highest reached, tends to liberate the coal ash in feathery, flying particles, which are picked up by the draft and carried along, lodging in eddies of the draft on the surface of the ware. All coals do not cause this difficulty equally. Some tend to fuse and stick together, and in this case the difficulty takes a new form—that of cleaning and reusing the checkers. The expense of setting up and taking down the checker work is to be considered also. With a kiln of this type it is a very difficult problem to burn glazed ware, largely due to the dust or ash settling on the sticky surface of the molten glaze..

Haigh Kiln.—The Haigh Kiln is one of the continuous variety, but it differs from most others in that the fuel is fed into fire holes on the exterior of the kiln wall, instead of being dropped in among the ware as just described. The kiln is usually built in a U shape, with duct connecting the two extremities. This open court permits of having doors for loading and unloading the kiln on both sides of the tunnel, and as the tunnel is fired from both the top and the sides it permits of an equal distribution of the heat over the cross section. The chambers are marked off by drop arches which come down into the kiln a matter of a foot or more, and act as a check or baffle to the gases flowing along the crown of the arch. The side firing is advantageous, in that it has a tendency to help bring up the temperature of the floor of the kiln equal to that at the top.

The same objections apply in general to the Haigh kiln as to the kiln first described, but it has some advantages over the other in the ease of heat distribution and less flying ash.

As stated earlier, the Haigh kiln in this particular instance is being used for burning roofing tiles and dry-press bricks in the same chamber. This is a practice not to be endorsed. Clay which has been worked in the plastic condition will develop a vitreous structure at a lower temperature than the same clay worked by the dry process. And again a thin

piece of clay ware can be fired in a shorter time than a thick piece. Hence, the idea of nesting thin plastic wares like tiles among dry pressed bricks, and expecting to burn both at the same time, is entirely wrong. One or the other must suffer as a result. It would be much better to set one chamber of bricks and another with tiles, for then each ware could be given a somewhat modified treatment in firing.

In summing up, neither of the continuous kilns mentioned can be said to be doing particularly high grade work in burning roofing tiles, but there is no reason why the continuous kiln cannot be made ideal for the burning of roofing tiles in this country as well as in Germany and France.

The proper kiln should be rather low, and not very wide; the fuel must not be distributed among the ware, but should be burned in separate furnaces, and fed to the kiln chamber as a gas.

The draft must be under full control by dampers, and should be created mechanically, so that it can be made constant or varied at will. The cooling chambers should be so arranged as to furnish heat for the drying and to assist in warming up the newly set tiles, before the combustion products are admitted to them. While the continuous kiln composed of separate chambers is more expensive to build and keep in repair, it will be found better for the burning of roofing tiles. The construction of a continuous kiln should be in the hands of a properly trained engineer. The problems involved are too numerous and varied to make it at all a safe thing for a clay worker to attempt, unless prepared as a constructing engineer.

SUMMARY.

In considering the best type of kiln for a roofing tile plant, the size of the plant and the provision for the regularity of operation are naturally of paramount importance. For small plants, with but little capital, and without means for storing up a winter's supply, or wet weather supply of clay, investment in a continuous kiln would not be at all warranted. It must be kept in constant operation, or its economy and its convenience disappear. The small, cheap, and autonomous periodic kiln has far the advantage for such a plant, even though it uses three or four times as much fuel. Among the periodic kilns, the rectangular are to be preferred to the round, on account of economy of space in setting. The draft distribution can be made virtually as good, and the slightly increased losses of radiation and slightly more costly building of the kiln will not be serious items in the cost of the product.

In large plants with ample capital, good clay storage, or a supply independent of weather, the continuous kiln, with all of the best devices for preventing poor draft distribution, using waste heat of cooling ahead

of the combustion gases, using furnaces which will prevent flying ash, and using mechanical draft, is unquestionably the proper one to install. The reduction in the cost of burning is what should control, where quality is not at the same time sacrificed. The roofing tile manufacturer, in order to compete with lower-priced roofing materials, will soon be compelled to make tiles cheaper than can be done in many existing plants.

The final cost of production can generally be best reduced by studying to handle the burning with ease and certainty and with the minimum quantity of fuel of the less expensive sorts.

CHAPTER X.

ROOFING TILE SLIPS AND GLAZES.

The coloring or glazing of roofing is not at all new. The art dates far back into history. Probably the oldest example we have of glazed tiles, are those from the temple of Hera, which was built about one thousand years B. C.[1] According to Graeber, in a memoir, these old tiles were covered with a black glaze. It is probable that the covering was a black slip like that used on Grecian pottery, and not a true glaze, as understood today.

Kashiwagi,[2] a Japanese antiquarian, of Tokio, has records of a green glazed tile of the normal pattern, which he claims is over one thousand years old. Morse also records the finding of tiles covered with a brown glaze at Bizen, Japan, known to have been made at least two centuries ago.

Persian[3] roofs from the thirteenth to the fifteenth centuries were covered with highly glazed tiles. While a few glazed tiles have been made in this country for many years, it has only been within the past decade that any particular attention has been given to the subject. With the introduction of polychrome architecture, there has been an increasing demand for glazed tiles in the various colors, largely greens.

SLIPS AND ENGOBES.

The coatings known as slips (in German and French, engobes) and those known as glazes, differ merely in degree of fusion. A slip is a coating, applied to a clay ware, which does not fuse in the subsequent burning process. It is usually a clay, or a mixture of natural clays, which on firing, preserves a burnt clay texture on its surface and fracture, and does not soften to the point of flowing, or assume the smooth surface of a fluid. It may be soft and porous, or steel-hard, or even vitreous, but its changes have been such as occur without flowing, or mingling by movement while at high temperatures. As stated before, slips as a rule are natural clays or mixtures of such, which vitrify at low temperatures, forming a more or less impervious coating. The purpose of a slip may be two-fold: 1st, to give a desirable color to a clay of otherwise undesirable color; 2nd, it may be used to give a smoother surface by filling up irregularities, and thus getting a tile which will remain clean longer.

[1]Morse, E. S. American Arch. & Builder, 1892. Vol. 36, p. 7.
[2]Ibid. Vol. 36 p. 5.
[3]Encyclopedia Brittanica. Ninth Edition, Vol. XXIII, p. 389.

Roofing tile plants using calcareous, glacial or alluvial clays, which on burning develop a light-pink, buff or greenish mustard color, are practically compelled to make use of slips to mask or cover the surface of their wares.

Natural Slip Clays.—For ordinary slip coloring, the requirement is for a clay which will easily disintegrate and beat up to a state of fluid suspension in water; which is naturally very fine grained; which will not shrink too much in drying, and hence will not crack or peel when applied in a thin coat to another clay already partly or wholly dried; which possesses a fine red color, when matured at a low temterature (900° C. or below), and remains good to as high a temperature as the body to which it is to be applied will require in burning; which develops a more or less glossy, but not glassy, surface; which will naturally wash clean by rains and offer the minimum opportunity for the lodgment of soot and dirt. Such clays are not common, and when found, acquire a certain value as a commercial commodity, being bought and sold by the ton or barrel. Good ones are sometimes even imported from Europe.

Two of the American plants are using the Helmstedt clay from Germany, which burns to a fine red at a low temperature. To cheapen the cost of the slips it has been the practice of late to substitute a part of the foreign material by some local clays. There is no reason why slips composed wholly of local clays could not be used. Two clays have been tried in an experimental way in the Department of Ceramic Engineering of the Ohio State University with promising results. One is found a few miles east of Columbus, and is known as the Bedford shale. The other is a soft shale from South Webster, Ohio. Both clays, when made into slips, burn to a very beautiful cherry-red color at their respective finishing points. The Bedford shale has a longer heat range than the South Webster shale. The drying shrinkage in each case is a little high, but by using a part of the clay in a calcined condition, and ground to an impalpable powder, this point could be corrected to fit any average roofing tile clay. While the Bedford shale in the quarry is in so hard a condition that it would need grinding and screening before it could be blunged into a slip, the weathered outcrop of it will often yield great quantities of fine soft clay which will blunge without grinding. The South Webster shale, as seen so far, could be blunged into a slip direct from the pit, but it would also probably need grinding when mined well under cover.

The usual practice at plants where slip clays are used is to ship in a considerable quantity of their slip clay once or twice a year, and store it in a dry condition, each day taking what is needed. This is put into a blunger, where water is added, and the charge blunged or stirred until the clay is thoroughly broken up and suspended in a thin, creamy condition. It is then sieved through a screen of from forty to one hun-

dred meshes per lineal inch, and stored in barrels or tubs, where it is allowed to settle. The supernatant water is then tapped off until the slip has the proper density. This varies, however, with each clay. A tub of the prepared slip is placed upon a bench at the end of the dryer, from whence the dry tiles are being taken. In some cases the slip is poured over the outer or face side of the tile only, by means of a dipper. In other cases the entire tile is immersed in the slip for an instant, not long enough to soften, but long enough for a layer of the suspended clay particles to be deposited on the tile by the absorption of the water. As soon as the tile is removed the water soaks into the tile, and it apparently dries, usually in a minute or two. The tiles then go direct to the kiln for setting.

In the past much controversy has occurred over the use of slips. This has come very largely from faulty slips and the misuse of the same. There can be no more objection raised to the use of slip clay on a tile than there can to the use of a true glaze, and in some respects not so much. The slip coat should be used as a true means of decoration, however, and not to hide a poor tile.

The application of a slip coat over the surface of a whitewashed tile is sure to end with bad results. The scum acts as an insulating barrier to the slip, preventing it from coming in contact with and fluxing fast to the tile body. Hence, in a short time after such a tile is exposed to the weather, water gets beneath the slip, and on freezing, shells or pushes it off. A very noticeable example of this defect can be seen on the roof of the Art Museum in Eden Park, Cincinnati, Ohio.

It has been claimed by makers of slipped tiles that their product does not become dirty on the roof as unslipped tiles do. This point applies chiefly to tiles of porous body. It does not apply to strictly vitrified tiles, which wash as clean with rain as any clay surface, glazed or unglazed.

The reason that a slipped porous tile will remain clean is that the slip, on becoming vitreous, or vitrified, acts in a sense like a glaze, allowing the tile to be washed clean by rains.

If for any reason a manufacturer has selected a clay which in itself does not burn to a good color, but otherwise makes a sound, perfect tile, there can be but one objection to his using a slip to give him a red color, viz., the chipping of the tiles in transportation and handling reveals the body color beneath the red surface, and makes an unsightly blotch on the color. This objection holds equally true for any kind of superficial coat, glaze, enamel or slip. The objection is of much more real weight in pottery and other wares which are to be handled at close range, than to a roofing tile or building terra cotta, which is ordinarily so far removed from the eye that small imperfections become invisible. Much injustice has sometimes been done in applying too exacting stand-

ards to the judging of these wares. Obviously the soundness of the body and the appearance of the product when in position are the two important criteria, and defects which cannot be recognized or seen, and which have no effect on the life of the product, should be ignored. On the other hand, there are strong economical objections to slipping—the cost of the slip clay itself, its preparation, the expense of applying the same, with the resultant breakage of a percentage of the tiles, which will certainly take place during the shipping, are all to be considered. There are so many natural red burning clays of excellent color that it would seem entirely unjustifiable to locate on and use a clay for roofing tiles which must be given a coating of slip to cover up its poor color. In localities where natural red burning clays are lacking it may be justifiable, but not elsewhere. The plants now compelled to use a slip on their tiles were in most cases established without adequate knowledge of the roofing tile business or of the clays they were to use, and the present owners as a rule have bought the plants in at forced sales after heavy losses had been incurred by their projectors. The present owners have, therefore, to make the best of what they have, and use slip as one way of doing so.

The use of a clay naturally burning to any other color than red is not known in the American roofing tile industry. It is a very common and important process in terra cotta manufacture, where every shade of browns, grays, yellows, whites and speckled mixtures of the same are used. There is not much more difficulty in obtaining clays which will form desirable light-burning slips than for red-burning slips, but the market now offers no opening for such materials.

Artificially Colored Slips.—The commonest practice in coloring slips has been to attempt to produce a better red color by use of oxide of iron in the slip. Sometimes salts of iron, like copperas, are employed. As a rule such attempts fail, either when applied to the slip coating alone, or to the entire body of the clay. As a rule the expense of such a course is too great, and the results are not satisfactory as to the color obtained. Instead of getting a good red, most generally a brownish or dirty gray is secured. Red oxide of iron changes to dark brown or black on heating, and does not act as a red pigment. Iron can be introduced in other forms which will color a clay red, but its use is costly and also leads to other defects. Manganese oxide can be used with success, but the color produced is dark, not red, and the expense again comes into serious consideration.

The use of colored slips other than red for roofing tiles has been up to the present practically unheard of. One plant, The Bennett Roofing Tile Company, of Baltimore, produced on a small scale a few shades of green in true slips, during the latter part of its career, but at no other plant was anything of this sort being attempted in 1908.

The use of colored slips for roofing tile is sure to come, however, and with its advent will be opened up a wonderful field for polychrome decoration to the architect. With colored slips, a soft delicate appearance, so much desired and but poorly imitated by most glazes, is available. Where stained wooden shingles are now used for roofing and siding purposes, it will be possible to use an everlasting absolutely non-fading material.

For dark colored slips, such as browns and blacks, the same clay that is being used for the body of the tiles, or any good red-burning slip clay may be used. By blunging into this clay, or better still grinding the clay to a cream with various per cents. of iron oxide for the browns, and with manganese oxide and a small amount of cobalt oxide for the blacks, these colors are readily secured.

The amount of coloring matter will depend upon its source and fineness of grain. For oxide of iron, there are two sources of supply, *first*, the natural red hematite or limonite ores, which yield a fine red color when ground to a powder. Of these the "Clinton Metallic," ground from the fossil Clinton iron ore of New York state, is an excellent type. There are several such on the market. Analysis of this ore, as furnished in ground condition for "mortar colors" and similar uses is—

Siliceous matter	15.37
Aluminium Oxide	4 42
Ferric Oxide	62.08
Calcium Oxide	6.85
Magnesium Oxide	3.15
Water and Carbonic Acid	8.08
Total	99.95

Second. "Venetian red" is produced by the calcination at low temperatures of ferrous sulphate, or copperas, or iron vitriol, which is a by-product in enormous quantities in the pickling vats of tin-plate mills. This copperas at lowered heat gives off its water and sulphuric acid and the spongy ferrous oxide remaining oxidizes into red ferric oxide, of great beauty of color. It is, however, always impregnated with undecomposed sulphuric acid salts, and is a fruitful cause of scumming in consequence. In composition, it is nearly pure ferric oxide, but its impurities are very detrimental.

Manganese oxide can be obtained in abundance from a number of dealers in heavy chemicals in this country. It is prepared for the brick trade, especially, in sizes ranging from twenty to thirty mesh granular powder, up to the finest floated pulp which cannot be measured by a screen. The commonly used sizes are twenty to thirty, forty to fifty, sixty to seventy, ninety to one hundred; and the floated or paste form. These powders are mostly ground ores of manganese, pyrolusite, wad, or psilomelane. They vary pretty widely in composition, not

only from brand to brand, but also in the same brand. The most reliable brands are said to be English and German, which vary very little in their character. The American producers can undoubtedly produce an article of the same quality and uniformity whenever they appreciate the necessity of doing so. Up to the present, they do not all seem to see the need of strict uniformity and chemical control of their output.

The composition of a standard brand on the market, as furnished by the courtesy of The Harshaw, Fuller & Goodwin Co., of Cleveland, Ohio, is as follows:

Analysis of Manganese Oxide.

Ingredients.	Ordinary.	Selected.
Peroxide of Manganese	84.44%	85.42%
Protoxide of Manganese	0.50%	0.83%
Peroxide of Iron	0.93%	0.86%
Oxide of Lead	None	None
Oxide of Copper	0.02%	0.02%
Oxide of Nickel	0.05%	0.05%
Alumina	1.71%	1.06%
Barytes	1.21%	1.41%
Lime	1.15%	0.88%
Magnesia	0.18%	0.04%
Potash	0.22%	0.21%
Soda	0.68%	0.58%
Silica	5.60%	5.45%
Carbonic Acid	0.70%	0.50%
Sulphuric Acid	0.418%	0.555%
Phosphoric Acid	0.360%	0.330%
Arsenic	None	None
Combined water	1.90%	1.75%
Totals	100.068%	99.945%

For the other colors, such as buff, yellow, blue, green, gray, white, etc., it is necessary to start with light or white-burning materials as a base, to which the various coloring oxides can be added to give the desired color.

The first problem is to prepare a white engobe or slip which will fit the roofing tile body and at the same time vitrify sufficiently to cause it to adhere tightly. It must not be so vitreous as to have a glassy surface or sheen.

An ordinary white engobe prepared of the following ingredients will require a much higher temperature to vitrify it than the average red-burning roofing clay will stand.

Kaolin	150
Flint	100
Feldspar	50

Hence, to soften it down to a point where it will vitrify at the desired temperature, a flux must be added. The one most available is some form of lead, either white lead (the basic carbonate) or an oxide, like red lead. Other ingredients, such as lime, more feldspar, or feldspar of more fusible variety, may be added to assist in lowering the vitrification temperature, but they are not sufficient without the use of lead.

After a white engobe has been obtained which will sufficiently mature and harden at the rather low temperatures at which the red roofing tile body-clays mature, and which fits the body as to shrinkage, the production from it of a series of colored engobes is a comparatively simple task. It is only necessary to add the raw coloring oxides to the base engobe, grind them fine together, and apply as an ordinary slip. The great advantage in favor of using slips instead of glazes is that the tiles can be faced or set in the usual way, no attention being necessary to prevent them from sticking. For other reasons to be discussed later, it is firmly believed and strongly advocated that the roofing tile manufacturer should devote more attention to slips than to any other mode of tile decoration or coloration.

At the laboratory of the Department of Ceramic Engineering of the Ohio State University, slips of a few of the more common colors have been developed with good success after being fired in an experimental way in the University kilns, and finally in the actual roofing tile kilns at several plants. It is deemed safe to give them out as starting points for others to use in developing similar slips for their own purposes.

Base Engobe.

White Lead (basic Carbonate of Lead)	17.80
Soda Feldspar from the Sparvetta Co.	25.40
English Whiting (Carbonate of Calcium)	1.90
Edgars Washed Florida Kaolin	39.70
Golding's Ground Silica (Potters' Flint)	15.20
	100.00

This mixture, well ground together in ball mills, and passed through a one hundred-mesh screen and fired at cone 02, becomes steel-hard, though it does not run or fuse in the least. It is of a creamy white. A better white might be secured by varying the kaolin, and perhaps the other minerals above. Coloring oxides can be added, however, without being at all affected by the lack of purity of the white color of the base engobe.

A good green was produced by adding ten per cent. (dry weight) oxide of chromium to the above base engobe.

A good yellow was obtained by adding ten per cent. of oxide of uranium.

A good light blue was produced with from two to three per cent. and a dark blue with six to eight per cent. of cobalt oxide.

Some excellent greens were produced by blending various proportions of the uranium engobe with the chromium engobe. The colors obtained were yellow or olive greens.

The amounts of the coloring oxides used in the above formulas are large, and hence the recipes would be expensive to use on a large scale. But the experiment has not been carried to its completion, and doubtless great improvements can still be made. For instance, instead of using the pure oxides direct, it would be better to mix them with glass-forming materials, and fuse them into a melt or fritt. These fritts, containing from twenty-five to fifty per cent. of the coloring oxide, and being themselves of a fusible nature, could then be ground to a very fine powder and added to the engobe. The result would undoubtedly be to obtain a more lively color with much less coloring oxide, and resulting economy. The details of these fritts have not been worked out, but in general, if soda, borax, a little lead, and a little potters' flint be used as a flux, the coloring oxides will dissolve or amalgamate freely. The proportion can be easily worked out by a few trials. The melting should be done in crucible furnaces where the materials can be kept covered and kept under treatment as long or short a time as is needed. The melts should be poured into water to crackle, then dried, and ground to an impalpable powder before use.

The work of properly fritting and making colored slips or glazes should be in the hands of a competent person, who has had training in ceramic chemistry. If the work is carried on in a systematic and economical manner, much money can be annually saved, which is now wasted in obtaining ceramic colors without a knowledge of the proper ingredients.

GLAZES.

The fundamental requirement of a glaze, as distinguishing it from a slip, is its fusibility at the working temperature. A hard glaze suitable for a body requiring a high fire, might act as a slip if applied to another body maturing many cones lower, and so also, a satisfactory mixture for a slip at a low heat, might fuse to a glaze if carried much too high. But, if the substance is not more than a vitrified solid when finished, it is a slip, and if it has been fused, it is a glaze. Of course, there are all manner of intermediates, which it is difficult to refer to either class with certainty.

Glazes are divisible into two main groups—the bright or glassy and the dull or stony. The former include the transparent glassy glazes, of the kind employed in table wares, and the opaque glazes known as enamels. The latter include the so-called matt glazes, and

certain others which are known as crystalline glazes, though they are also matt. Between the transparent brilliant glassy glazes, and the dead, lusterless stony matt glazes, every possible gradation of luster,color,and surface texture may be found or produced, and it is impossible to classify all of these intermediates with accuracy into either one or the other of these divisions.

Bright Glazes.—These glazes are the common or typical kind of silicate surface coating. For a long time they were almost the only kind made. Dull or matt glazes were only produced as failures in the attempt to get bright ones. But as has happened many times before, man has converted his failures into successes, and in the last few years the use of the dull glaze has greatly increased. From the artistic point of view, as a coating for roofing purposes, bright glazes are now considered a complete failure. The reflection of light from their mirror-like surfaces is so strong under ordinary conditions that it is impossible to look at the roof, except at certain angles. The color cannot be seen at all, except on dull days or from special points of view. This very practical difficulty led to the introduction of the matt or dull glaze into the roofing tile field.

Nevertheless, roofs have been covered with bright glazed tiles, and doubtless will be again. The general type of the glazes employed is known as the raw lead glaze, and usually the more fusible varieties are required, as the red burning tile clays mature at relatively low temperatures.

Such glazes may be represented in chemical formulas as between the limits—

$$\left.\begin{array}{l}1.00 \text{ to } 0.50\ PbO\\ 0.00 \text{ to } 0.20\ K_2O\\ 0.00 \text{ to } 0.20\ CaO\end{array}\right\} 0.10 \text{ to } 0.25\ Al_2O_3 \left\{ 1.25 \text{ to } 2.25\ SiO_2\right.$$

The ingredients most commonly employed in making such glazes are

Red Lead or White Lead.
Feldspar or Cornish Stone.
Whiting
China Clay or Ball Clay.
Flint

A typical raw lead glaze, falling within the above limits, which will melt and run bright at a temperature beginning about cone 08, and which will often remain good to a temperature as high as cone 02, has a formula as follows:

$$\left.\begin{array}{l}0.85\ PbO\\ 0.05\ K_2O\\ 0.10\ CaO\end{array}\right\} 0.10\ Al_2O_3 \left\{ 1.20\ SiO_2\right.$$

This glaze (No. 1) could most easily be made up of the following ingredients:

White Lead	68.98	Unit weight 318.
Ground Feldspar	8.74	
Whiting	3.14	
China Clay	4.05	
Potters' Flint	15.09	
	100.00	

Another typical raw lead glaze, which will mature at a little higher temperature, beginning at about cone 05 and remaining good to cone 01 or 1, is as follows:

$$\left.\begin{array}{l}0.70\ PbO\\0.15\ K_2O\\0.15\ CaO\end{array}\right\}0.20\ Al_2O_3\ \left\{1.90\ SiO_2\right.$$

This glaze (No. 2) could most easily be made up of the following ingredients:

White Lead	52.10	Unit weight 345.9
Ground Feldspar	24.00	
Whiting	4.50	
China Clay	3.80	
Potters' Flint	15.60	
	100.00	

A third typical raw lead glaze which will begin to mature at about cone 02, and will remain good to about cone 3 or 4 is as follows:

$$\left.\begin{array}{l}0.60\ PbO\\0.20\ K_2O\\0.20\ CaO\end{array}\right\}0.25\ Al_2O_3\ \left\{2.00\ SiO_2\right.$$

This glaze (No. 3) could most easily be made up of the following ingredients:

White Lead	45.40	Unit weight 340.9
Ground Feldspar	32.61	
Whiting	5.86	
China Clay	3.78	
Potters' Flint	12.32	
	99.97	

By taking fractional parts of a unit weight of either glaze, any desired mean between any two may be obtained, viz:

0.8 x 318 (unit weight of No. 1) =	254.4
0.2 x 340.9 (unit weight of No. 3) =	68.18
	322.58

which makes a glaze (No. 4) one-fifth of the way between the two extremes, and which will be harder than No. 1 by about one-fifth of the difference in fusing point between No. 1 and No. 3.

With these starting points, a little experimenting will often lead to the production of a satisfactory simple, bright, raw-lead glaze. When the problem involves fitting the glaze to a body, and remedying crazing and other defects, or matching colors, the matter becomes too complex to deal with by rote, and it should be put into the hands of one acquainted with the theory of the subject.

These mixtures all mature at their respective temperatures to form bright transparent glazes. If applied over a red body, the red color will show through; if over a buff body, the glaze will appear yellow, though the yellow is due to color of the buff body showing through the clear glaze.

Should it be desired to make a glassy green glaze, using one of the above type glazes, it would only be necessary to add various per cents. of copper oxide. It will, however, be found impossible to produce satisfactory bright green transparent glazes over a red body direct. The red color of the body will show through and interfere with the desired color. To overcome this, it is necessary either to use an opaque glaze or enamel, or else first to slip the tiles with a white or buff slip or engobe and then apply the colored transparent glaze upon them. The true color of the glaze will then persist.

The amount of copper oxide required to make one of the above glazes into a good strong green is about one and one-fourth per cent. Lighter tints are obtained of course with smaller quantities, even one-fourth per cent. will be quite clearly green, on a clear light background. No advantage will be found in running the copper higher than two per cent., unless it is desired to produce bluish "gunmetal" effects, in which case the amount may have to be three per cent. or above.

A number of plants are making a very satisfactory bright glaze, variously known as "red brown," "fox red," "mahogany" or "tea-pot." This glaze, to be at its best, should be applied on a body which naturally burns to a light red or pink, and requires a red slip to strengthen its color to a saleable point.

The base of the glaze can be the same as any of those just given. To it is added one per cent., or a little less, of iron oxide, or better still from two to three per cent. of manganese oxide. The glaze when applied over the red slip coating of the tiles seems to dissolve or take into solution parts of the slip clay, thus allowing the color of the main tile-body to show through feebly in irregular streaks, while the parts not dissolved show a dark red color. The combination of the light and dark red presents the appearance of the grain to be seen in mahogany wood.

These red-brown glazes nearly all show beautiful spangled crystals in places—not on every tile, but in frequent instances. These crystals are due to the excess of the iron dissolved in the glaze. The glaze while fluid takes up the oxide of iron from the slip clay in addition to what

has already been added, and becomes supersaturated, so that upon cooling small glittering flakes of some iron compound crystallize out.

Other colors which can also be produced from these same glazes are plain blue with oxide of cobalt, plain brown with oxide of manganese, and plain orange yellow with oxide of uranium. The cobalt is a very powerful oxide, and only a few tenths of a per cent. are needed. Uranium is also used sparingly on account of its cost. One per cent. or less is as much as would be used ordinarily. Manganese produces a fainter color and several per cent., even up to five per cent., may be needed. Of course, mixtures of the different oxides produce mixtures of their colors—cobalt and copper produce blue-greens; cobalt and iron produce black; cobalt and manganese produce purple, etc. The field open to the experimenter in producing new shades is practically endless.

Matt Glazes.—With the introduction of the dull glaze, which does away with the painful brilliance of the early types, has come a much wider use of glazed tile roofs. Color schemes are now possible which could not be realized with bright glazes, or which could not be seen even if produced.

The true matt glaze is one whose chemical composition is such that on cooling it cannot retain a glassy structure, but changes to a stony or crystallized mass instead. There is a group of matt glazes which are not to be distinguished readily from true matts, but which are merely immature or partially fused. These come very close to slips or engobes, though generally they are more completely fused than the latter. The true matts, however, are much more satisfactory to work with, have the widest temperature range, give the best colors and leave fewer defects in covering the ware properly.

The surface of the true matt glaze is crystalline or rough, often not to the eye or the feel, but if examined closely with a glass it would be seen that the surface resembles the peel of an orange or an egg shell. This roughness causes an absorption or breaking up of rays of light, instead of a reflection back as from a mirror, so that what the eye sees is a solid mass of color, soft and velvety to look at.

The roofing tile manufacturers have not found it a very easy task to produce matt glazes of satisfactory color and surface texture, which would mature at the low temperatures at which they are mostly compelled to work. Matt glazes in other industries, maturing from cone 2 up, are common, but the latter are expensive fritted glazes, not suitable for a product like roofing tiles. In order to bring the maturing point of the cheaper matt glazes down to about cone 06 or 05, more fluxing ingredients like lead oxide have had to be resorted to, and with this increase has come trouble from the glaze drying up through volatilization when fired in the open kilns, and also bright glazes are produced by a little extra heat, and the matts would vary in degree of their mattness.

The following formulas have been tried on several roofing tile clays with a fair degree of success. They require about cone 02 to mature, which is a little higher than desirable:

$$\left.\begin{array}{l}0.70\ PbO\\0.10\ K_2O\\0.20\ CuO\end{array}\right\}0.34\ Al_2O_3\ \left\{1.60\ SiO_2\right.$$

Add 0.10 to 0.12 CuO for color.

This glaze (No. 5) can most readily be prepared by grinding together the following batch:

White Lead	50.80
Ground Feldspar	15.40
Whiting	5.50
China Clay	17.05
Ground Flint	8.65
Copper Oxide	2.60
	100.00

This glaze gives a rather light green matt, which would be improved with a little more yellow color.

A glaze which will mature at a slightly lower temperature, about cone 05, is given below.

$$\left.\begin{array}{l}0.45\ PbO\\0.12\ K_2O\\0.35\ CaO\\0.08\ ZnO\end{array}\right\}0.28\ Al_2O_3\ \left\{1.90\ SiO_2\right.$$

Add 0.12 CuO for color.

This glaze (No. 6) could most readily be prepared by grinding together the following batch:

White Lead	36.40
Ground Feldspar	20.80
Whiting	10.85
Zinc Oxide	2.05
China Clay	12.80
Ground Flint	14.15
Copper Oxide	2.95
	100.00

This glaze produces a matt green, and on account of the lead content being lower than No. 5, it should stand the heat treatment with less volatilization. If the copper oxide is left out of the glaze, it will be a rather yellowish white and not at all pleasing. In the place of the copper oxide various amounts of cobalt oxide may be added for blues, iron oxide and uranium oxide for yellows, manganese carbonate for purples and browns, and nickel oxide for gray. The amounts of the various oxides to use will vary, but aside from cobalt, which requires very little, the quantities are not very dissimilar to the amount of copper used in the preceding batch.

Beside the production of matt glazes by the proper means; viz., proportioning the ingredients correctly and giving the glaze the proper

heat treatment, there are a number of ways of dulling the surface of of a glaze and thus producing what for lack of a better name we may term artificial matts. One of these processes is to add raw sand or ground calcined clay into matt glazes in various per cents, giving the glaze a very rough and stony appearance. For some purposes this method, it is believed, has decided possibilities for good. In reproducing the moss-covered tiles so much admired in Europe, this is probably a good mode of attack.

A similar mode consists in artificially roughing the surface of the clay by cutting it with a wire, and allowing the rough surface formed by the dragging of the grains to remain unsmoothed. This of course could only be applied to flat tiles like shingles.

Another method is the use of the sand blast on the surface of a bright glaze. The glass is cut away, leaving a rough dull finish, very much liked by many architects for certain color schemes. The blasting machine is the same as is used by the glass manufacturers in producing etched or frosted glass. It consists of nozzles through which a powerful current of compressed air is blown, carrying sharp glass sand in suspension. This sand strikes with such force that it readily cuts away the surface of any substance, metallic or non-metallic. The tiles to be treated are laid together the same as if placed on the roof, on an endless belt, which moves very slowly, carrying them under the nozzles of the blasting machine. The speed requisite to allow the sand to cut away the surface of the glaze as the tiles pass by is determined by experiment. The sand used must be renewed quite frequently, on account of its wearing away to dust under the severe treatment to which it is subjected. While this method is rather slow and costly, it gives a characteristic and not unpleasing finish.

Another and very objectionable way of producing a matt finish was found in use at one plant. Tiles with bright glassy green glaze were being washed with hydro-fluoric acid, one of the most powerful and dangerous acids known, whose special peculiarity is its power to attack silicates. The vapors or fumes of this acid are an irritant poison, and for this reason its use should be permitted only under special conditions, with the most perfect ventilation, and every precaution for the safety and health of the employes. Its use under other conditions and without these safeguards is little short of criminal.

This powerful acid when applied to a glazed surface at once attacks the silicates that have been formed, dissolving or disintegrating them until the surface is minutely rough or stony looking.

It is a curious fact that in cut-glass factories this same acid is used for the exact opposite effect; i. e., for polishing a piece of glass which has a dull or frosted surface after it has been cut. The difference comes in the lack of homogeneity in the glaze, some parts dissolving so much

faster than others, while glass is practically all the same thing and dissolves about equally.

The possession of the mere recipe or formula of a glaze which is in successful use in one plant is but a very small step toward the installation of a successful glaze in another plant. Some glazes are in use which can be applied to wares of considerable variety, and at a considerable range of temperature. But this is not the common thing at all, and most glazes have to be operated under such special conditions that they would be practically useless if transferred without alteration to another works. They are often traded or sold as if they were a commodity of value, and then subsequent failure gives rise to ugly suspicions or charges of bad faith in the transfer, whereas, in fact, the causes of the failure are purely natural.

The fitting of a glaze to a body, i. e., its adjustment so that its rate of contraction in cooling or its expansion in heating up are about like that of the body upon which it is borne, is one of the great stumbling blocks in the path of the glaze maker, amateur or professional. There are many factors entering into its settlement, but the commonest, most useful, and in most cases a sufficient mode of control is by variation of the silica content of the glaze. For instance, in Glaze No. 2, if the glaze were cracking or "crazing" on the wares when drawn from the kiln, the silica in the glaze might be cautiously increased. The higher the silica can be pushed, without sacrifice of other necessary properties, the safer the glaze is from this trouble. But too much silica might produce the reverse phenomenon of crazing. viz., "shivering," where the glaze flakes off, carrying chips of the body with it, and producing a very undesirable surface. The silica must be reduced to overcome this defect. These additions or subtractions of silica to a glaze may and probably will affect its melting point, and the results cannot be considered as proved until the glaze has been fired at the temperature it requires after its alteration. Very many errors are made in this way by glaze makers altering the glaze composition and failing to alter the heat treatment at the same time.

Besides the question of being made to fit, it should also be so constructed that it will have a relatively wide heat range; that is, it should remain workable and good over a considerable increase in temperature. In regular roofing tile kilns, the temperature from top to bottom sometimes varies as much as two or three cones, and a like difference may exist from side to center of the kiln. It is plainly seen that a glaze which passes through maturity and becomes overfired within the temperature range of one or two cones, will not prove at all satisfactory under such burning conditions. There should be at least a range of four cones in which the glaze is good, and even more would be better.

Mechanical Preparation of Glazes.—Every step in glaze production should be methodical and systematic. This does not mean that changes

may not be introduced, but that changes must not be allowed to creep in without the knowledge or consent of the glaze-maker.

Weighing Out.—Each ingredient should be weighed separately, one at a time, in a scoop or weighing box, and the weights counted and recounted. When dumped into a common receptacle, one ingredient on top of another, there is much more danger of the ingredients getting mixed in taking out excess quantities of one or the other. *The sum of all the ingredients, after assembling all in one receptacle, should be reweighed and the collective weight of the batch should equal the theoretical sum of the individual weights of the various ingredients.* If this custom is kept until it becomes instinctive and unconscious, many serious errors in the mixing room will be avoided.

Grinding Glazes.—In general, it is important that the ingredients of glazes should be most thoroughly blended by fine and intimate grinding together. Especially is this the case where coloring oxides are added raw to a glaze batch, because the glaze is almost certain to be "specky" if not ground. In fact, a better way to insure the fine subdivision of the coloring matter is to grind it with a small quantity of glaze, or of some one ingredient of the glaze, separately, until impalpable when tested between the teeth.

The prepared color slip may now be added to the glaze, and with comparatively little grinding become well distributed. The function of the grinding is to secure uniformity in distribution and uniformity in fusion. With coarse particles of dissimilar minerals making the glaze, the effect would be crude and patchy.

There have been, and doubtless will be again, instances in which very interesting and admirable color effects and surface textures on glazed wares are obtained by the use of unground or poorly ground glazes, or where some one ingredient is left unground or added to the mill just before a charge of glaze is removed as finished. But, in the broad way, there can be no doubt that it pays, from the standpoint of cost and perfection of product, to reduce the glaze to a fine-grained, homogeneous state before use.

On the other hand, too fine grinding is possible. Glazes may be ground so fine that they will crack and shrink in drying on the surface of the ware like a fat clay would, and these marks may not heal over in the subsequent fusion. In general, if a glaze is ground long enough so that it will pass through a sieve of 150 meshes per lineal inch without leaving any residue on the sieve, it is fine enough. If raw coloring oxides are to be added, they should be preground as fine as possible before adding to the glaze batch. This insures good color distribution, without necessitating such long grinding of the entire mass of the glaze.

The mills for glaze grinding are of two types, the old, familiar buhr-stone type and the recent ball-mill type. There is difference of opinion among potters as to which produces the glaze at less cost

in grinding, fineness being equal. It would be a laborious problem to definitely settle this contention. But it is certain that the quality of the work done by either is good enough. The ball mills are steadily replacing the older type, chiefly on account of their convenience and ease of cleaning.

Iron grinding mills, such as are used by paint grinders for incorporating dry paints and oils or varnishes, are occasionally used by glaze grinders, and also iron-ball mills.

For some colors, especially the dark ones, very little, if any, trouble would be experienced from this practice, but for the light colors much trouble will result. The metallic iron of the mill is ground off by the continual rubbing of the discs or the impact of the balls, and enters at once into the glaze as a part of it. When the glaze is applied and melted, the iron will form specks and discolorations.

Ball mills of large size should be lined with vitreous lining of stoneware or porcelain bricks, while the smaller ones are usually made of solid porcelain jars. The balls used in large mills for the grinding of glazes are, as a rule, flint pebbles gathered on the beaches of northern France. These pebbles are usually oval in shape, well rounded, and vary in size from an inch to three inches in diameter. In the smaller mills the pebbles are usually marbles made of porcelain. The dust worn from the linings and pebbles of porcelain or flint-lined ball mills is composed of silica or silicates, and being similar to some of the ingredients of the glaze, is absorbed without ill results, but in unlined iron mills this is not the case.

The consistency, or thickness, of the glaze slip is a matter of importance. If too thick it will form clots, or "blobs," of glaze in spots and along edges and in corners. If too thin it will not form a thick enough coat without more than one dipping, and will thus cost more labor. No law can be laid down, either in weight per pint or in specific gravity by hydrometer, by which a correct thickness can be determined. Different glazes vary so much in ingredients that they do not weigh the same per pint when at exactly the same relative fluidity. For any single glaze, the weight or specific gravity is constant at the same fluidity, and these measures are easily available for the guidance of the men. The practical sense of the dipper is usually sufficient to keep the glaze about right in this respect. The application of the glaze to the ware is done in very much the same way as slips are applied. As the dry tiles come from the dryer, they are taken to the glaze room, where a large tub of the prepared glaze is ready. The tiles are then taken one by one, and coated on the outer surface by carefully pouring the glaze over them while held in a standing position, allowing the excess to drain back into the tub. The tiles are then placed on racks or shelves, to allow the glaze to dry sufficiently for handling.

The Setting of Glazed Roofing Tiles.—Glazed roofing tiles are at present set in very much the same way as the unglazed. In plants where the unglazed wares are set solid, without fire-clay supports or boxes, the use of boxes for the glazed part of their output is general. Only one plant was found in which glazed tiles were set solid, without boxes, and the results in this case were of a very low grade.

It is the usual practice to set the glazed goods in the lower half of the kiln, where they are more protected from the flame or flying coal ashes.

Figure No. 167 shows the method of setting glazed tiles in a kiln where the balance of the ware is set without supports.

General Discussion of Burning Conditions.—The limiting conditions of the glazed roofing tile business today is the one-fire burn. Manufacturers want to produce their glazes in the same burn with the regular ware. They think they are obliged to do this by the present prevailing prices for glazed tiles. The temperature required by roofing tile clay is usually relatively a low one, and the composition of the glazes that can be used is limited in consequence. None of the roofing tile plants are burning as high as cone 1 regularly, hence only fusible glazes are possible. Highly fusible glazes can only be commercially produced by use of lead oxide, boric acid in some form, or the alkalies, potash or soda. Of these, the alkali potash is expensive, and as it does not do its work materially better or differently from soda, it is practically out of consideration. Soda is abundant and cheap and effective, but it cannot be used satisfactorily in a raw glaze. It must be previously melted with silica, or some equivalent substance, and converted into a glass no longer soluble in water, in order to work well as a glaze ingredient. The cost of this preliminary melting or fritting, and the grinding which follows, makes the use of a fritted glaze objectionable.

Boric acid is open to the same objection as soda, viz.: solubility. A few insoluble forms could be made, but they are not commercially readily available, and moreover boric acid costs twelve to fifteen times as much as soda.

This leaves lead oxide as the chief, in fact the only really convenient and accessible resource of the glaze-maker for low temperature raw glazes.

Lead oxide is quite volatile at red heat and above, and its losses, depending upon the duration and temperature of the firing, are apt to be large. The longer the firing continues and the higher the temperature reached, the greater loss of lead from volatilization. This loss of the chief active flux brings about a rise in the maturing point of the glaze.

To prevent this glaze from becoming "too hard" by the volatilization of the lead, potters have long since adopted the plan of placing their ware in saggers, or fire clay boxes, the interior of which are well

coated with a glaze rich in lead oxide. These saggers are piled one above another and the joints coated with clay, making comparatively tight receptacles, so as the heat increases and the lead volatilizes, its vapors are held in the sagger, where they soon saturate the inclosed space and further volatilization is thus largely prevented. The ware itself is thus protected from the loss of much of the oxide lead from its glaze, because the "sagger wash" has already supplied all that the space will contain.

With the roofing tile manufacturer, the case is very different. He sets his ware in an open kiln, or at best in kiln boxes, where the lead oxide that volatilizes will be quickly carried out of the kiln along with the gases of combustion. There is no completion to the process of volatilization, because there can be no saturation of the moving current of air; therefore, it is necessary for the glazes to be loaded with a surplus of lead, to allow for the loss and to be sure that enough will remain.

Another trouble that very frequently happens in kilns using coal, is the sooting of glazes. The ware set in the open boxes becomes coated with soot or tarry matter in the early part of the burn. Now if the kiln should be burned pretty rapidly, or with a shortage of air, this deposited carbon will be caught and retained in the glaze. This may subsequently change the composition of some of the glaze ingredients and is very likely to ruin or spoil the glaze by forming bubbles, pin-holes and blisters. The potter, in saggering his ware, reduces and sometimes prevents the deposition of soot.

Many clays contain minerals, especially iron pyrites, that upon being heated give off gases. In the case of one-fire wares like roofing tiles, these gases pass through the coating of glaze on the surface, and in many instances give rise to bubbles in the glaze, as well as other defects. Single-fired goods are much more subject to this trouble than those which are "biscuited" in one fire, and glazed in a subsequent burn. The two-fire process however, costs very much more, and is now thought too expensive for roofing tile manufacture. Unless the manufacturer has a clay which will glaze satisfactorily by the one-fire process, he will either have to get a clay which will, or not attempt to produce glazed tiles.

It has been shown by experience that lead glazed goods should be protected from contact with the kiln gases, and to prevent volatilization they should be inclosed. Roofing tile manufacturers are doing neither. They are not only applying their glazes to a raw body, which is a handicap to the process of glazing, but are also setting the glazed wares so that they are subjected to all the changes taking place in the kiln fires, and generally in the bottom half of the kiln, where they get the moisture and waste gases from the wares above. Under these circumstances, is it any wonder that the losses are enormous on glazed

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wares? They usually condemn the glazeman, change fuels, try every glaze receipt that comes within their reach, in fact do everything but the right thing.

While it is true that the roofing tile manufacturer should not undertake to set his glazed ware in saggers, he can at least burn them in separate kilns, designed for this particular work. Muffle kilns, built after the plan of those used by terra-cotta manufacturers, are the next and proper step in the direction of improved production of glazed roofing tiles. As a matter of convenience and economy, this kiln should be rectangular, narrow and low, and not of large capacity, so that it may be fired frequently, and thus not hold up orders requiring a small amount of glazed ware. It should be set with kiln blocks in the muffle, the same as in the regular kiln. The muffle merely acts as one big sagger, keeping the flame, soot and ash off the glaze, and at the same time confining the atmosphere inside the muffle, so that it might become partly saturated with lead vapors, thus reproducing or largely preventing the losses from volatilization of lead.

The roofing tile industry will never produce glazed ware in an economic manner, either as to cost or quality, under the present prevailing conditions. Those manufacturers that first grasp this situation, and properly equip themselves for the production of strictly first class glazed tiles at a price where they can be more widely used, will be the ones to get the business.

Comparison of Slipped vs. Glazed Tiles.—There are a number of advantages in favor of the production of tiles covered with colored slips, rather than with colored glazes, either bright or matt:

First. The slip is much less costly than the glaze, pound for pound, from the fact that much less lead is required.

Second. The slip has a wide heat range over which it is merchantable. The green slip, of which the formula was given earlier in this chapter, matures in the neighborhood of cone 02, but the same slip when fired to cone 8 still remained perfect, the only difference being that the color was better, and more intense, and the surface of the slip was smoother, bordering on a matt glaze. What is true of this slip is true of the class as a whole.

Third. The slips will not give as much trouble from volatilization or blistering or crazing or any of the common physical defects.

Fourth. The slip is much more likely to prove a durable coating, so far as the weather is concerned, when applied to unvitrified tiles. Seger says, "No one should use glazes, unless he knows that his ware has the necessary degree of durability to carry them. It is known that soft burned tiles, when they are exposed to the weather after glazing, generally shell off after a short time. Hence they are not improved by glazing. For this reason, it must be understood that

tiles must be hard burned if they are to be glazed, or at least medium hard, and it is better if they are vitrified, but under no circumstances should they be soft."

The reason for these statements can be very easily understood. A soft burned tile, which has an impervious glassy coating on its face side will have opportunity to absorb moisture from one source or another through its unglazed side. If this moisture freezes, it tends to force its way out of the tile in both directions from the center, and an enormous force is brought in play on the under side of the glaze, very frequently shelling or spalling it off. With a well vitrified tile, no such trouble will occur. The slip however is preferably not made entirely vitreous, and the water which freezes in the tile can escape through the slip the same as through the body, leaving both tile and slip unhurt. On well vitrified tiles, the slip should also be vitrified, but not glossy. No frost danger will come to any vitrified tile by reason of the use of either glaze or slip, but for a soft tile, a porous slip is the preferable coating.

Fifth. The slip coatings are duller in surface texture than any ordinary matt glaze can be made, and hence give the greatest freedom from reflection of light from the roof, and stand for their natural color in any and all lights better than a glazed roof can do.

Sixth. The setting of slipped wares is much simpler, as the surfaces should not become vitreous enough to stick. Glazed tiles offer a serious problem in this respect.

On the other hand, the advantages of the glazed tiles are:

First. They use less coloring material than slips will do to obtain an equal coloring effect, for the coloring oxides in the slip do not flux sufficiently to really develop their colors to advantage, and hence must be used in larger quantity. In the production of many colors this would be a serious item.

Second. The glazed tiles, even rough matts, if of good quality, will present an impervious surface to the weather and will not be readily stained by soot and dirty water which flows over them. A slip will ordinarily be porous enough to discolor easier from this cause, and cannot be cleaned again. Any surface, even of glass, is not proof against the gradual incrustation of greasy or tarry soot, and no roof will remain permanently clean and bright. But a well glazed tile roof can readily be cleaned by scrub brush, soap, and hose, and a slipped roof can not.

The periodic cleaning of glazed terra cotta and enameled brick buildings by washing is now becoming a recognized necessity if the true character of the surface is to be maintained, and in this connection roofs will also need the same treatment.

It is not the intention or desire to discourage the use of glazed roofing tiles. But if used, the plane of their manufacture should be raised, and they should be made as perfect in proportion as enameled bricks or glazed terra cotta, which is not now the case.

There is however, a broad field for dull matt glazes, applied to the proper kind of bodies. They should be used as a means of decoration only,and not as a protection to the tiles, for experience has shown that if a tile is not itself safe, glazing will not make it so.

CHAPTER XI.

STOCKING AND SHIPPING ROOFING TILES.

Drawing Kilns.—The removal of roofing tiles from the kilns is a simple operation incapable of much variation. At present, the work is wholly done by hand labor, and usually of the unskilled sort. The manner in which the tiles are set; i. e., with or without supports, or with or without strips, will of course vary the work in some of the minor details. Where supports are used, it becomes necessary to take the units down as the kiln is being emptied. To gain working room in the kiln, it is necessary to carry or wheel the blocks from the first five or six benches outside, and there pile them up. For the balance of the draw, the blocks can be stacked against the side walls, leaving a space through the center of the kiln for wheeling the ware out, and beginning the loading later on. Where tiles can be set without supports, the extra work of moving the kiln blocks at each burn is avoided, and the work of drawing can proceed rapidly from the start. The difference in time required to empty a kiln set with and without supports, is about as two is to one in favor of the latter method.

No matter how the tiles are set, they are taken down from the benches in handfuls of four to six tiles at a time, and placed on a wheelbarrow, such as is made for brick works. The tiles are placed on ends or sides as their forms may require. Spanish tiles, for instance, are loaded on end, two rows to a barrow. Interlocking and shingle tiles are for the most part placed on the side or edge, one row wide and two tiers deep, with common plastering laths between the tiers.

A wheelbarrow thus loaded with interlocking tiles will carry about thirty to forty tiles, and with plain Spanish tiles, about twice that number.

In kilns where the tiles are set self-supporting, it requires about one minute on the average to load a barrow, while in cases where the block system is used, it will require from two to three minutes for the same load. In either case, two men as a rule work on the same load. Part of the time, one man standing on lower benches passes the tiles down to the second man, or wheeler, who places them on the barrow; the balance of the time, when working on the lower benches, both men place the tile directly on the load.

It was observed at the plant of the National Roofing Tile Company, at Lima, Ohio, that portable four-wheeled trucks were being used to convey the tiles from the kiln. These trucks would hold from four to

six wheelbarrow loads each, and a permanent runway of plank had to be used for them. Unless on a level or down grade, two men were needed to move a load. As between the wheelbarrow and the truck methods, much can be said in favor of the former, at least for ordinary distances. The facility with which a wheelbarrow can be moved about from place to place, the narrow spaces needed in which to maneuver it, and the comparatively large loads that one man can move, all tend to make it a very convenient and satisfactory tool for the work.

With the building of larger plants it is quite possible that it may be found advantageous to use a conveyor system for the unloading of roofing tile kilns, such as is done in some brickyards at present, but such a provision would seem out of place on any plant now in existence.

Sorting or Grading the Ware.—The barrow loads of tiles are wheeled to a sorting table, or low bench, in the yard, where the wheeler leaves them, bringing an empty barrow away when he returns. The sorter has three or more wheelbarrows conveniently arranged about the table, upon which he places the tiles as he sorts them into firsts, seconds or thirds and into the various shades. As fast as a barrow is filled with tiles of one grade it is wheeled away by another man, and piled up in the car, stockhouse or yard, as the case may be.

A good sorter, under ordinary conditions, can grade tiles as fast as two wheelers can load and bring them to him from the kilns. In a few of the yards the tiles are wheeled from the kilns, and stocked at once on general stock piles by the wheelers, the sorting being done at a later period by the regular sorter. This method makes more handling of the tiles, and has no advantages in particular to justify its use.

The sorting or grading of roofing tiles on most of the yards is very poorly done. In some cases no further attention is paid to this feature than to throw out the obvious culls. Such a practice should be severely criticized, for tiles shipped after this kind of sorting are sure to prove unsatisfactory on a first-class roof, and are a detriment to the industry as a whole. The conditions in every plant at times are such that the temptation to ship everything that can by any possibility pass muster is very strong. Sometimes the demand for tiles has been above the supply. Sometimes, in a weak and struggling plant, the urgent need of money has brought about poor sorting, in order to get shipments on the way so as to be able to draw on the consignee earlier. The policy of high-grade sorting justifies its cost in the long run beyond any question.

The careful sorting of tiles into shades is a matter of far less importance than the grading as to soundness, freedom from warpage or structural defects. There is a widespread and well-founded demand at the present time for a liberal range of shades in one order. In fact, calls are not uncommon for a much greater variation than is produced in the normal product of a kiln of ware. Architects have gotten away from

the use of closely shaded colors, either in bricks or tiles, and it is not likely that the demand for close matching of shades will return, at least in this generation. Tiles, like bricks, when closely shaded prove monotonous in appearance, while a variegated roof or wall has a texture or character far more pleasing to the eye of a cultured observer.

Yarding or Storing Roofing Tiles.—Up to the present time the carrying of large stocks of roofing tiles has been for the most part unknown. Many of the plants in the past have for the greater part of the time been behind in filling their orders. In such cases the stock piles, if any, represent only seconds and culls.

While some of the plants have built large stock sheds, the larger number of them make no provision at all, except limited shed room for the trimmings. With a closer grading of the ware and larger outputs, it will probably become the practice to house all first grade ware at least. Where yarded in the open, the tiles soon become very dirty, and in the winter they freeze together in the piles, thus making shipments next to impossible.

The method of piling the stock in the open is quite clearly shown in the accompanying illustration, Figure No. 178, where both interlocking and Spanish tiles can be seen.

Interlocking tiles are generally stacked on edge, with plastering lath between to keep the tiles from rolling and the courses level. Boards are usually placed on the ground for the first course of tiles to rest upon, otherwise the superimposed load will sink them down into the dirt.

In Figure No. 179 can be seen the method of storing auger-made Spanish tiles. It will be observed that this company has provided a shed for the protection of its stock. The tiles are yarded by standing on end about four courses high, with lath or strips between.

The stocking of hip rolls and cresting is accomplished in much the same manner as for tiles. The larger sizes stand upon end, about four courses high. The smaller sizes that will not stand solidly are in some cases stocked in racks or bins, piling them up so that they cannot fall. Larger pieces, like finials and special ware, are in some cases stored on racks or shelves, but it is not uncommon to see them left standing about the yard, to become begrimed with soot and dust until they look like second-hand ware before they are shipped.

Packing and Shipping Roofing Tiles.—With very few exceptions the roofing tile manufacturers of this country ship practically all of their output to distant markets, thus entailing the loading of the ware into freight cars. On the ideal yard, the loading switch is depressed to a point where the floor of a car is at the stock-yard level. This is very important, because the tiles are in all cases wheeled from the yard into the car, and in those plants where the men are forced to wheel the

Fig. 178—Stock Yard Showing Manner of Piling. Chicago Heights Plant, Ludowici-Celadon Co.

Fig. 179—Storage Shed for Spanish Tiles. Cincinnati Roofing Tile & Terra Cotta Co., Cincinnati, Ohio.

tiles up inclined runways, smaller loads will surely be wheeled and the loading will prove more expensive.

In loading a car, the tiles are placed in the same position as for storing on the yard, i. e., the interlocking are packed on edge and the Spanish as a rule on end. The car loader begins by placing a row of tiles from side to side of the car at one end, leaving about a two inch space into which straw is packed tightly. In addition straw is wedged in at either end of each row to prevent lateral motion. Plastering lath are then placed on top of each row before the second or next one above is put in. When about four courses have been placed in the first row or tier, either straw or a lath frame is placed between the first and second rows as the latter is being filled. Both ends of the car are filled, until the open space between the doors is all that remains unfilled. Bracings are then put in across the space as in figure No. 180.

To prevent the piles from being knocked over by the jolts in transit, as a general rule only plain tiles of regular shape are packed in rows and tiers as described. All trimmings, such as finials, crestings and special pieces, are packed on top of the regular tiles, while small pieces, like small cut hip and valley tiles, and tower tiles, are frequently packed in barrels in order that they may not be broken or lost between the car and building at the unloading point.

Packing Material.—For the greater part, the packing material is either wheat or oat straw, preferably the latter on account of its softness. The ideal material, however, is the so called prairie or wire grass, so extensively used for packing bananas. This material has very great toughness and at the same time is very soft and pliable. It makes the work of packing easy. At some points, sawdust and shavings have been used; of the two, the latter is the better, though neither is satisfactory. The constant jarring of the car causes the sawdust or shavings to work down, leaving the upper courses loose, in which case many of the tiles will be broken.

In the loading of roofing tiles, it is usual to work a double crew, that is, the loading of the car is started simultaneously in each end. To properly carry out the work, there are required two packers, two helpers, two wheelers and one man at the stock pile assisting in loading the wheelbarrows. With the above number of men it is possible to load and pack a car in ten hours. Such a car would contain about seven thousand (about fifty-four squares) interlocking (French A pattern) tiles, and in addition the usual amount of cut work and trimmings to go with them.

Under favorable conditions the above figures are high, but are such as would obtain where the tiles must be wheeled up from the yard to the car level. Where a depressed loading track is used, these figures can be cut materially. If a liberal supply of packing is used it increases

the time of loading. In rough figures, the cost of loading, packing and bracing tiles will fall between fifteen and twenty-five cents a square.

Local Deliveries.—In plants like those at Detroit, Cincinnati and St. Louis, it is possible to deliver many orders by wagon haulage. In

Fig. 180—Car Loaded with Roofing Tiles, Showing Method of Bracing.

such cases the tiles are loaded in the wagon box or bed very much in the same manner as they would be loaded in cars, a very liberal supply of straw generally being used. However, the Cincinnati company, making a well vitrified tile, has delivered many hundreds of squares by wagon without the use of any straw whatever. The tiles (Spanish) were loaded by carrying the tiers as rows from end to end of the wagon, rather than across, with wooden strips between the upper and lower rows.

CHAPTER XII.

THE LOCATION AND DESIGN OF PLANTS FOR ROOFING TILE MANUFACTURE.

In considering the organization of a new roofing tile factory, the questions to be considered are: first, Where shall it be located? And second, How shall it be constructed?

LOCATION OF PLANTS.

Before considering the intimate questions of design at all, the engineer should first inquire into the fundamental or limiting questions on which success or failure will ultimately depend. These factors are:

First. Capital sufficient not only to build the plant in such a way as to take advantage of all possible economies in operation, but also to operate the plant during those trying months or years when a new concern is competing for a market and establishing a reputation.

Second. A suitable and sufficient supply of raw materials, including clays, fuel and water.

Third. An adequate supply of labor and facilities for housing the same (if not adjacent to a town).

Fourth. Proper shipping facilities.

Fifth. An adequate market within commercial reach.

It is not intended to list these items in the order of their relative importance. As a matter of fact, all are essential, and unless all of these qualifications can be met, the enterprise cannot hope to succeed. Discussing each in turn:

Capital.—Deficient capital is the cause in nine out of ten cases where clay-working enterprises fail. The conditions at one time permitted a plant to start with small beginnings, and work along with but little expenditure, gradually growing strong by turning the profits back into the business. The same is still true in a general sense, but the difference comes in what is now considered necessary to a small or modest start. In this day of combinations, the difficulties met by any new plant in breaking into the market are not to be minimized, and it is an absolute requirement that the new enterprise shall be able to produce wares of acceptable quality at as low cost as the big and powerful competitors who already have the business. If the plant has been under-capitalized, and is doing business at a high labor or fuel cost, to save cost in equipment or kilns, then its chances of keeping its head above water during the first year or two are very

poor. If the plant is new, modern, up-to-date, and saves labor and fuel at every turn, it has an excellent chance to succeed in spite of any competition, for its competitors will not for any long time cut prices below their own cost of production. The cost of production is thus the crucial matter with the new plant.

Fig. 181—General View of Plant of Huntington Roofing Tile Co., Huntington, W. Va.

Working capital is just as necessary as that which is tied up in equipment. No clay manufacturing industry can expect to start off with the production of high percentages of good saleable ware. The clay industry is peculiarly susceptible to little misadjustments and any and every stage of the process may give trouble in unforeseen ways. No other industry, except gold mining, has broken up so many cocksure novices, and mulcted so many investors. For these reasons, every plant is likely to run at a disadvantage for some weeks or months, possibly even a year or two, while conquering the difficulties of its material, and learning to give it the individual treatment necessary. During this period, the losses are usually irksome and hard to bear. Any firm that has put its all in its plant, and is living from hand to mouth during the probationary period, is in a bad way. In general, a clay manufacturing company should have a working capital ranging from fifty to one hundred per cent. of its plant-cost, to make its chance of success assured.

Raw Materials.—An adequate raw material supply is an undisputed *sine qua non* of success. Its importance cannot be overestimated, but in the past the error of investors has been in seeming to consider this item as being of itself sufficient to assure success. The facts are that clays suitable for the manufacture of most of the common clay products are abundant and well distributed. Their presence on a piece of land is so common a thing that of itself it does not scarcely constitute an asset. Of course, many special cases occur where a good clay bed

is an asset of value. But it is commoner by far to find that a company could establish itself on any one of a dozen or a hundred farms in a given district, and obtain from any of them an adequate clay supply. The limiting condition is found in the transportation facilities, or the labor supply, or the freight rates to market, etc.

The proper attitude of mind, therefore, on the part of the promoter of the plant is to *assure himself of the satisfactory qualities of the clays on some certain tract of land, of which the other factors of success are known in advance to be safe.* No clay property itself is good enough to justify putting a plant on it, unless the other qualities also support the proposition independently.

The quality of the clays needed for the roofing tile industry have been discussed at some length in Chapter III, and while it was shown that no clay unites all the good qualities, and that every material has some drawbacks, it was nevertheless shown that there was no great difficulty in deciding whether a clay's good points overweighed its faults.

The principal feature to be urged at this point is the necessity of making a careful and scientific study of this question before going deeper into the project.

The material should not only be thoroughly tested as to its physical and pyrochemical behavior, but the extent and uniformity of character of the deposit should also be carefully studied.

Instances are not uncommon where a fine outcrop of clay has pinched out or changed in quality and become worthless, almost within sight of the original opening.

In the selection of clays of the alluvial and glacial class for roofing tile purposes, even more precautions should be exercised than in shales. The variability in their conditions of deposition render their physical properties and chemical composition liable to constant or immediate changes in short distances or depths. Shales and fire clays are generally deposits of large superficial area, and change their character much less often or less rapidly than clays of glacial or alluvial origin.

A poorly designed or badly constructed plant can be gradually improved and made to answer its purposes, but if a plant is once located upon a poor or treacherous clay nothing can be done to rectify this trouble—it exists as a permanent handicap.

Cases are on record of plants having been located upon materials entirely unfit for or unsuited to the manufacture of roofing tile. Whether the cause or reason was a false idea of economy in not expending the money to make a thorough and complete survey and test before locating cannot be stated. Strange as it may seem, otherwise shrewd business men, for the sake of saving a few hundred dollars spent in properly testing and exploiting a clay property, will risk thousands of dollars in building a plant on materials they do not know to be good. While a few plants established upon such unsatisfactory clays have continued

to make tiles, by dint of abundant capital and good business management, many others have failed outright after expending large sums of money in trying to overcome their original mistakes.

On the question of fuel supply there are two points of view, viz., quality and price. The ideal fuel as to quality is natural gas. Very few plants in the past, however, have been so fortunate as to be within reach of this perfect fuel, nor is it to be anticipated that those in the gas belts will long be able to afford it. It should be reserved for better uses. Crude oil is also used to some small extent in the industry, but

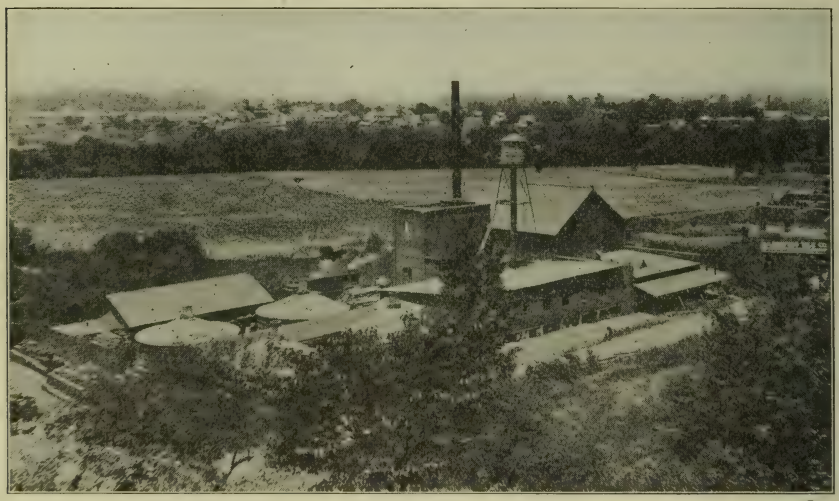

Fig. 182—General View of Plant of the United States Roofing Tile Company, Parkersburg, West Virginia.

its supply is also limited and not likely to remain long available for such uses. Where available, crude oil is scarcely second to natural gas in the quality of work it can do and in its fuel value, but it is very much inferior in convenience and cleanliness. It is ill smelling, dirty to handle, and requires much adjustment at the burners.

One plant is so situated that pitch pine is available as the fuel supply, but such conditions are so rare that they do not call for consideration here.

Under existing conditions the greater part of the tiles produced are burned by coal in furnaces directly attached to or a part of the kiln. Unquestionably coal will be, in the future even more than at present, the fuel used. Hence in selecting a new site for a roofing tile plant it becomes very necessary to investigate the conditions of supply as well as the price and calorific power of the coal.

The establishment of a roofing tile plant in a new district, where coal is brought in from long distances, and therefore is high in price, will be doubtful unless it can be shown that the handicap on the coal

is offset by the saving of freight on the shipment of the finished product to the market. Tiles go at higher rates than coal, and will weigh several times as much as the coal required to make them, hence it may be a real economy to ship the coal; but these conditions must be carefully studied, and nothing taken for granted, before establishing a plant.

The quality of the coal also comes into consideration. Some coals cannot be used for clay product manufacture on account of low calorific power, high sulphur, bad clinkering properties, lack of flame, too much flame, etc. Roofing tiles require relatively low temperatures, and hence permit the use of some coals which would be ruled out for pottery or fire clay goods.

The water supply is a matter often overlooked, but of vital importance. Roofing tiles do not require the pure supply that is important in white ware industries, but the abundance and the nature and amount of its contained solids is important. It should be a good boiler water. If not, the cost of a treating plant must be added to the equipment, and the cost of chemicals, labor and supervision must be allowed for in running expense. A clay plant uses water to at least twenty-five per cent. of the weight of its output daily, and often more, so that many tons of water per day must be provided.

Labor.—A considerable amount of skilled labor will be required for the various departments. The skilled labor will ordinarily have to be imported to the vicinity of a new plant. Modelers, moldmakers, pressers, mitre cutters, etc., cannot be created or trained rapidly, and they are usually secured around terra cotta plants and potteries or other roofing tile plants and brought to the new works. The task of welding the heterogeneous mass of skilled workmen into a compact, organized, co-operative body, where each is willing to do his share for the common good, is one of the burdens of the manager. It involves selection, culling out mischief makers, promoting men of good character, teaching local men to fill vacancies, smoothing down jealousies, etc.

But aside from this most interesting phase, the social side of the situation must be considered. Good men cannot be secured, or at least kept long, under conditions involving poor food, poor quarters, poor schools, bad moral conditions, unfit surroundings for their families, etc. If a new company is established in the country, it means that housing, stores, churches and social amusements must be provided if a good class of men is to be attracted.

The actual conditions of labor in a roofing tile plant are favorable compared to most of the structural material industries. The unit weights handled are not large, and men are not under the heavy physical strain involved in brick or sewer pipe manufacture. The cars are lighter and easier handled, the kilns are smaller, the firing period shorter, the firing not so excessive, etc. These conditions all make it easier to procure

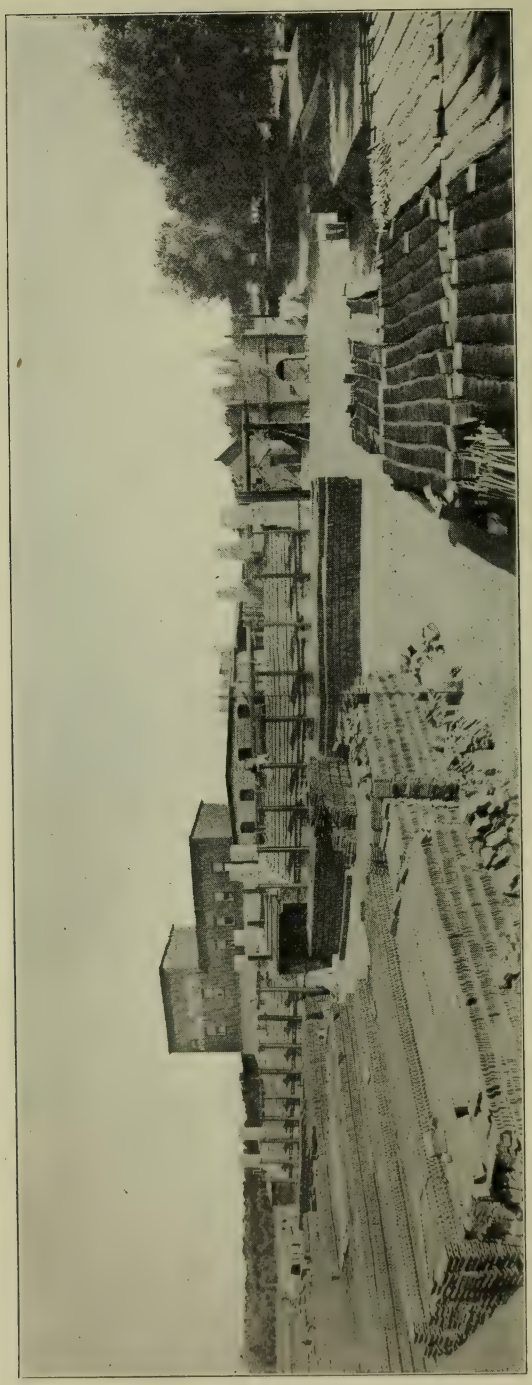

Fig. 183—General View of the Plant of the Western Roofing Tile Company (Since Taken over by the Ludowici-Celadon Roofing Tile Co.), at Coffeyville, Kansas.

and retain native American labor. The brick industry has very largely followed the large metallurgical industries in using gangs of imported laborers from southern and eastern Europe, but it is hoped that the roofing tile business may be saved for our own people.

Transportation Facilities.—A railroad is essential. Considering the fact that at least ninety-five per cent. of all roofing tiles made in this country are shipped by rail, it is very important that this point be well looked into before selecting a final location. Outside of locating on a trunk line or one of its tributaries, or better still, at a junction point where competing lines are accessible, it makes very little difference as to the exact locality for the plant. There are so few existing plants, it becomes necessary to ship the product to great distances in any case.

The roofing tile plants of Ohio are shipping their products from coast to coast, and from the gulf to our northern frontier. Of course, a location near a large market or city is to be preferred over one at a greater distance, provided other conditions are equal.

Market.—The greatest market for roofing tiles at present is in the larger cities, in all sections of the United States. Many tiles, however, are used in the smaller towns and county seats. The chief competitor of tiles so far has been slate. When the time comes that roofing tile plants are more numerously distributed over the country, so that shorter hauls and less freight will be attached to each tile roof, then will the tile market expand and fill every field, even to country dwellings, where slate or shingles now prevail. At present there are sections of the United States where tiles are used more extensively than in others, and this can be charged directly to the cost of tile delivery to the backward sections. The rarity of a tile roof is not due to any popular dislike of it, nor to any objectionable features. They would be universally used but for the excessive cost, which has to be made high to cover the long average haul by rail from factory to consumer. Hence it is firmly believed that the chances for success of a roofing tile plant, as far as the market is concerned, are practically as good at one point as another, provided the wealth of the communities are approximately equal. There are of course poor districts, where no large market for anything exists. But, wherever people are prosperous, there is room for this industry. There are vast areas of the United States that are as yet untouched by the roofing tile industry, and such points should make exceptionally fertile fields for wise and conservative promotion in this line. The great South and Southwest seem especially favorable.

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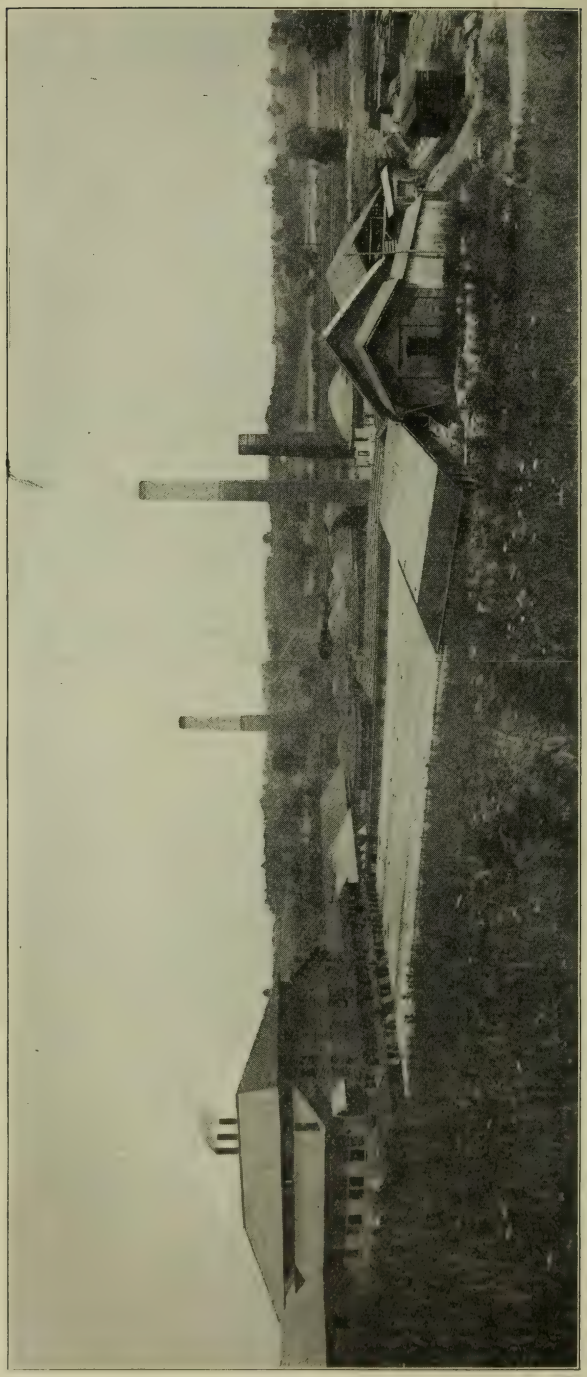

Fig. 184—General View of the Plant of the Ludowici-Celadon Co., at New Lexington, Ohio.

PLANT DESIGN.

Having duly considered these essential conditions of location, the more intimate and practical questions of plant design must be taken up. In designing a plant for the manufacture of roofing tiles, the ceramic engineer is confronted with a problem of somewhat greater intricacy than in the design of a plant for the manufacture of building bricks, paving bricks or sewer pipes and hollow wares, for two reasons: *First*, the ware is of thin cross-section, which necessitates the use of more care in the preparation of the clay, and in the handling throughout the various stages of its manufacture. *Second*, The problem involves manufacturing not one size and shape of product, as in brick works, or a dozen or two as in pipe works, but scores. No two orders are apt to need the same equipment of extras and trimmings, and filling each order causes a change in the material passing through the plant. Many orders are for parts never called for before, and not likely to be called for again, and in this sense, any order is a problem to be solved. Of course, the main roofing material is confined to from three to six varieties in most plants, in some even to one or two, but the trimmings are capable of endless variation. The plant design must therefore provide for elasticity in the kind of output.

In other respects the factors to be considered in the design of the plant are not dissimilar from those of other clay plants.

The Influence of the Type of the Clay.—The design of the plant will be governed very largely by the raw material selected, viz.: whether a shale or a plastic clay. In the case of a shale, the grinding facilities will have to be much heavier, the screening will be more carefully done, and generally to a finer size; there is less necessity of storing large quantities of dry clay in the summer for use in the winter, so that stock sheds may be reduced or cut out; it may be necessary to provide means for the storing or aging of the clay after pugging to develop plasticity enough, etc. In the case of a soft plastic clay as the base of supply, aging may not be required, but large storage capacity for dry material for winter use will be necessary.

Influence of the Kind of Tiles.—In addition to the type of the clay, the form of the tiles will enter very largely into the proper design of the plant, because it involves the selection of the manufacturing machinery. A shingle and Spanish tile plant would be equipped with auger machines of large size and high power, for expressing the small narrow ribbons of clay at a relatively stiff temper. Their outfit of presses would be confined to trimmings presses.

An interlocking plant on the other hand would use a small light auger machine for making blanks, and an array of heavy pentagon presses.

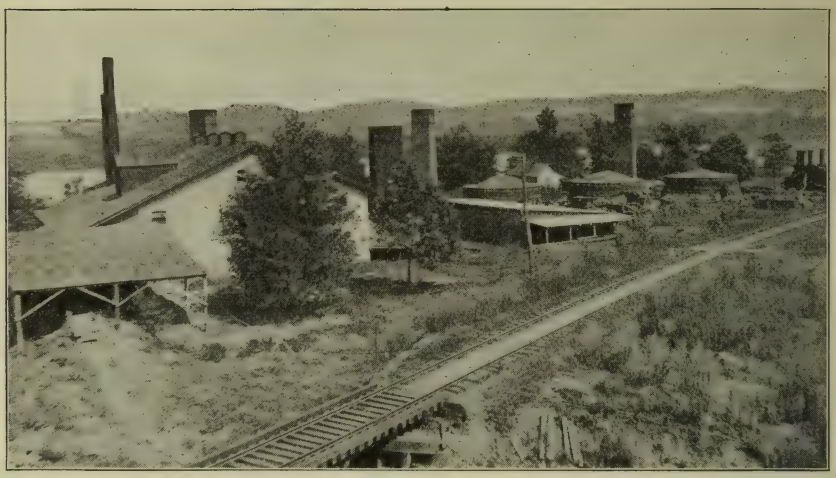

Fig. 185—General View of the Plant of the Murray Roofing Tile Company, at Cloverport, Kentucky.

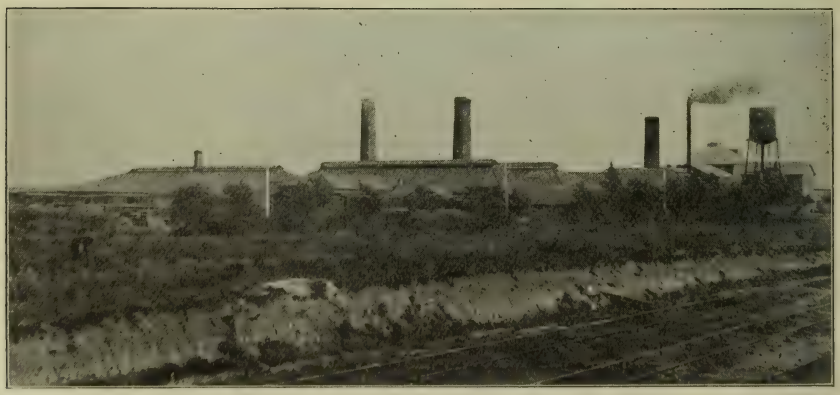

Fig. 186—General View of the Plant of the Ludowici-Celadon Roofing Tile Company, at Chicago Heights, Illinois.

Existing Plants no Criterion.—In a study of the existing roofing tile plants in this country, it is very noticeable that little engineering has been used in their design. For the most part, they are the outgrowths of very small beginnings, and have grown by accretion, additions being made from time to time at the points of least resistance, until many of them are a conglomerate, very badly arranged for future growth or present economical operation.

The explanation of this state of affairs can be traced in many instances to the fact that these same plants were established upon the wreck of some bankrupt brick or drain tile plant, which in the nature of the case would be ill adapted to the purpose. Successful plants have in some instances been developed upon such beginnings; success under such conditions reflects all the more credit upon the management, but it emphasizes the fact that if these poorly arranged plants have been able to prove profitable, how much more so would a properly designed plant have been.

Design of Plant to Meet Given Conditions.—Figure 187 inserted at page 991 is submitted as an illustration of the way in which this problem may be met. It is necessarily designed to meet hypothetical conditions, but these have been made as probable as possible. The problem selected was to design a "combination" plant; i. e., one which could produce any of the standard shapes at will. It could run on shingle tiles, Spanish tiles and interlocking tiles and make the necessary trimmings for each. For the most part, such plants are one-press plants, Hence, in this design, the object in view has been to use as little machinery for the output as possible, but to operate each machine to its full capacity all of the time, and in addition so to design the plant that its output could be increased in the future with the least expense, and at the same time without interfering with the original lay-out and operation of the portion already built.

Raw Material.—The raw material has been assumed to be a soft alluvial clay, of which thirty to thirty-five tons per day would be required.

Winning.—This daily tonnage would no doubt prove too small for the employment of a steam shovel. Hence clay gatherers similar to that illustrated in Chapter IV would be used, in connection with a car and cable haulage system to bring the gathered clay from the field to the stock shed. It is not economical to use the clay gatherer for transportation of the clays for any but the shortest possible distances. The clay, after being dumped into the cars, would be quickly transported from the field to the disintegrating machinery, or dumped into the storage shed for use during the winter months.

Storage.—The storage shed would be equipped with overhead track in the center, giving ten to fifteen feet dumping room below.

Under the center of the floor, extending from end to end of the shed, a belt conveyor would be installed. This would be covered by a floor of short pieces of plank, easily removable, so that the opening from the clay pile to the belt could always be kept close up to the foot of the pile, so that gravity would do most of the work of getting it onto the belt. One man in the stock house could feed the clay fast enough, and with very little shoveling. The conveyor would deliver at the foot of a vertical cup elevator, which in turn would deliver it to the grinding machinery.

Grinding.—For this purpose differential disintegrating rolls would be used, consisting of a relatively large, low-speed roll, against which would operate a small high-spe d roll. This first pair of rolls would not seek to grind the materials very fine. The action on the clay consists not only in crushing, but in shredding the caked flakes which have been crushed. The clay, after passing this pair of rolls, would drop into a second pair of large, rather low-speed rolls, which would carry the crushing to a much finer point, and deliver the product in a fairly uniform condition. From the second rolls the clay would drop into a pug mill. Should the clay be too dry, water would be added at this point. The clay, after passing through this pug mill, would drop upon a third set of crushing rolls, set extremely close together in order to crush the remaining hard particles. After issuing from these rolls, the clay would enter a combined pug-auger machine.

Forming the Ware.—The die of the auger machine would produce a bar of any desired shape, either for tiles or for blanks. Up to the auger machine the machinery is designed to work continuously. Since the plant is to be of the combination type, and not of sufficient capacity to use a double set of machinery, it would be necessary to operate the auger machine on various tiles or blanks, changing the die from time to time.

For the manufacture of interlocking tiles the plant would be equipped with one pentagon press, which would require in the neighborhood of six thousand blanks per day. With a good auger machine this number of blanks could be run in one-third of a day. Thus in order to run the auger continuously at proper speed, it would furnish the interlocking blanks three times as fast as necessary, and a storage room (so marked) for blanks would be necessary. By the use of this storage it becomes possible in two days to gain enough blanks in storage to keep the press busy the balance of the week. The bar, upon issuing from the auger machine, would be cut into blanks of the proper length by a simple reel cutter, and conveyed by the separating belt to the press and storage room. The press would be fed direct from the belt on the two days while blanks were being run, and the excess blanks not used by the press would be stored in the blank room.

At the end of the second day's run on interlocking blanks, the die and cutting table for either shingle or Spanish tiles would be substi-

tuted, and the machine would operate for the following three days on either of the latter shapes. In the case of Spanish tiles, they would be placed three deep on pallets carried by the Spanish table, and thence to the dryer cars. These cars would be transferred by the track back of the storage room, as indicated in the design. As each car received its load, it would move forward to the transfer track in front of the dryer, and thence to the proper tunnel. In the manufacture of the shingle tiles the operation would be the same, except that the Spanish cutting table would not be used, and the tiles would be taken direct from the off-bearing belt and placed at once on the dryer cars.

On the sixth or last day of the week the shingle or Spanish tile die and cutting table would be removed, and others substituted for the manufacture of special shapes and blanks for the trimmings press. In addition, it would be necessary to prepare the clay for use in the terra cotta room where the hand pressing and modeling is carried on. This clay would be conveyed by a belt conveyor direct to this room, where it would be stored in the bins indicated, and blanketed to keep it workable for the ensuing week. This clay is run at a different and softer temper than the clay used by the tile machines.

By the above scheme it is possible to operate the plant with one string of machinery and one crew of men and keep each machine working to its full capacity all of the time, thereby securing the greatest efficiency. There would be some handling of clay a second time in the interlocking department, and while it would be possible to have a separate and smaller auger machine operating exclusively and continuously on interlocking tile blanks, it would not be as economical and satisfactory as the plan suggested. It would not only call for an increased investment, but would require a considerable extra expenditure of power and more or less of one man's attention. In addition, the machine would have to be operated only partly filled with clay, thus producing a weak blank. In the plan proposed, if the future expansion of the plant required the installation of more presses, it would then become practical to install a second auger machine, using one expressly for blanks and the others for shingle and Spanish tiles.

For the return of scrap clay it will be noted that a belt conveyor has been indicated beneath the floor extending from the terra cotta room along behind the presses, past the cutting tables, to the auger machine. This scrap clay would be elevated at this point and passed only through the third set of rolls. This clay having been previously prepared would not need to pass through the entire string of preparing machines a second time after the manner of the raw material from the field, but would be sufficiently distributed by one pair of rolls and the pug mill of the auger machine.

Proposed Output.—The output per week for the machinery provided for in the above scheme, when operated as suggested, would be about as follows:

The interlocking or pentagon press would make in a week's run under ordinary conditions, about thirty thousand tiles. The auger machine would in three days' run turn out thirty thousand Spanish tiles or thirty-six thousand shingle tiles. On the sixth day, the auger machine after running sufficient soft clay to supply the terra cotta room for a week's work, and the necessary blanks for the trimmings press, could in addition make from one thousand to three thousand feet of bell-shaped hip rolls, or their equivalent in some other ware.

The trimmings press would work continuously, and in a week's run would make from twelve hundred to three thousand feet of cresting, or large hip rolls, the amount depending on the size.

The ware from the terra cotta room and the hand press, owing to its varied shape and character, would be hard to estimate, but would average about five tons per week.

Dies and Moulds.—For the greater part, the dies and moulds for this plant would be made of plaster. In order to have the point at which they would be made accessible, a space (marked plaster room) has been set aside in the corner of the terra cotta room, convenient to the presses and for the terra cotta moulds as well. This room would be furnished with a double-screw press, benches, sinks and water fixtures and other necessary equipment for plaster work. In a plant of the proposed size, one man would make all the necessary dies and moulds. In larger plants, a die-and-mould maker would have to be provided for each department of the work.

Dryer.—The dryer for this plant would consist of six double-track tunnels, one hundred feet long, operating on heat derived from the products of combustion emitted from boilers and kilns after passing them through regenerative stoves, and heat from the cooling o the kiln except when it was working on the continuous plan. When working as a continuous kiln, there would be no available heat for the dryer from the combustion products of the kiln.

In addition to these sources there would be added a set of steam coils using the exhaust of the engines and pumps. This last source of heat, with the addition of live steam, could be used in starting the dryer after a shut-down, or at times when the supply of waste heat from the kilns might be lacking or inadequate.

To operate this dryer, and to furnish a perfect draft for the kilns and boilers, there would be required two suction fans. One would draw the combustion gases from boilers and kilns through one of the regenerative stoves, and discharge them into the open air. In the meantime, the dryer fan would be drawing the fresh outside air through the other

stove, where it would become heated to the necessary degree for drying, and then forcing it through the various tunnels of the dryer. A third fan might be necessary to exhaust the moisture-laden, cool air from the other end of the dryer.

Dryer Equipment.—Assuming that the clay to be used would dry safely in the form of roofing tiles in twenty-four hours, twelve thousand pallets would be required to handle the output of the pentagon press for a two days' run. The cars necessary to hold this output would be about sixty in number, which would fill three dryer tunnels or six tracks.

For the Spanish tiles, produced on a two days' run, there will be needed seventy-five hundred pallets, three tiles being placed on each pallet. The cars necessary to care for the two days' output would amount to forty, filling four tracks or two tunnels of the dryer.

As stated before, the dryer was to have six tunnels, and as five of them have been used to care for the Spanish and interlocking tiles, there still remains one tunnel, holding twenty cars, for the special ware like cresting, terra cotta, and other shapes.

In addition to the pallets required to care for the Spanish and interlocking tiles, there would be needed thirty thousand pallets for the shingle tiles, and about five thousand special pallets, for eave and ridge tiles and other patterns.

It would not be necessary to have an increased car or dryer capacity to care for the shingle tiles, from the fact that the shingle tiles would replace an equivalent amount of Spanish tiles, hence, the same cars and drying tunnels would be used for each pattern.

In addition to the regular dryer there would be needed a small rack dryer in the corners of the terra cotta room, for the drying of large and intricate terra cotta finials and special shapes.

The heat necessary for this dryer could be derived from the same source as the larger dryer. An underground duct carrying the heat from the main heat flue of the large dryer to the proper point of delivery in the small drying room, or a small steam coil fed with exhaust steam from the pump, electric light engines or other minor supply might be profitably used.

Kilns.—Up to this point, but little departure has been made from the usual everyday practice, save in the matter of the heat supply for the dryer. In the matter of the kiln design some radical changes, which would make the plant more efficient and economical to operate, are recommended:

First. The kiln should be of the continuous type, the construction, however, permitting operation as a series of periodic units if desired.

Second. The kiln should be operated with producer gas as the

fuel, except when fired on the periodic plan, when coal, fired in furnaces attached to each chamber, would be used, at least in part.

Third. The draft necessary to operate the kiln would be by suction fan, rather than by stack.

Fourth. The heat from cooling kilns would be partly used to preheat the chambers of ware in advance of the fire, and partly to preheat the air for combustion, as is customary.

Taking up the first point, the reason for the selection of a continuous kiln is the very great fuel economy, which runs from one-third to one-fifth of the consumption in good periodic kilns. The first cost of the continuous kiln may be somewhat higher than that of an equivalent kiln capacity in favorably sized periodic units. The difference in this respect should not be great, however. The kiln is designed so that it can be operated either way, but it would be most efficient when operated as a continuous one. The firing, when on the periodic plan, would take place in the furnaces at each corner of the chamber as shown. In case these furnaces did not furnish ample heat, some top firing could be resorted to, or temporary furnaces might be installed in each wicket.

While it is questionable whether the use of producer gas would be materially different in cost from burning coal direct, there are many points in its favor. Wyer[1] gives some of them as follows:

First. With regenerative appliances an unlimited intensity may be obtained. *Second.* It may be produced from the cheaper grades of fuel, and still make more available heat than is possible with the costliest fuel used on the ordinary grate. *Third.* No more skilled labor is required than with grates, the tendency being to decrease this. *Fourth.* Centralization of furnaces is obtained, thereby making it easier to handle the fuel by mechanical means. *Fifth.* Elimination of clinkering in the kiln, thereby decreasing the heat losses and wear on the kiln. *Sixth.* Steady maintenance of a uniform temperature. *Seventh.* More uniform burning. *Eighth.* Better combustion. *Ninth.* The mildness of the gas flames will insure the best results for the ceramic product under treatment.

These statements of advantages are mainly made from the standpoint of the mere production of temperature by the combustion of the gas. They do not look at the question from the standpoint of the chemical effects of the heat on the clay, nor from a deep knowledge of what the chemical conditions in clay firing actually are. The second, third, fourth, fifth and eighth points are of greater weight than the first, sixth, seventh and ninth. The intensity of temperature which it is possible to gain by producer gas is in no sense an advantage in low-fired wares like roofing tiles, nor is the indisputable ability to maintain

[1]Wyer, S. S. Gas Producers and Producer Gas, p. 201.

uniform temperatures hour after hour necessarily an advantage. Uniform burning may very easily require alternations of higher and lower temperatures, which are naturally obtained in coal firing, and not so easily where the fuel is controlled by a valve. Also, producer gas is intensely reducing and if not handled well will blacken the wares worse, rather than less, than coal firing.

There are also some other factors which must be considered.

Producer gas from bituminous coal is loaded with vapors of tar, which carries a not unimportant part of the total calorific power of the coal, and which will condense out if cooled below about 200°. This tar is thus lost so far as its heat value is concerned, and is worse than lost, for it fills up flues and pipes, causes valves to stick, and has to be removed generally at considerable cost. If removed by washing, so as to be recovered and sold, the tar has a ready value, and makes up for the heat value it has abstracted, but the gas is now much reduced, and will no longer ignite except in a red-hot fire box, and burning conditions are made much more troublesome by the gas easily going out with slight changes of pressure, etc.

Producer gas, washed or unwashed, has not yet been used with satisfaction in periodic kilns on account of the fireplaces being cold in the start. On continuous kilns, the ease of application is very greatly enhanced, and beyond the disposition of the tar but little trouble is met.

While producer gas has not been employed in this country for the burning of roofing tiles, it is firmly believed that when it becomes better known it will find a ready and open field in the tile industry.

The use of mechanical draft has already passed the experimental stage in the roofing tile industry of this country. The excellent results obtained by its use leave little if any argument against it. It is positive at all times. It is possible by the use of draft gauges to systematize the burning to a far greater degree of certainty than is possible by the variable draft of a chimney. In the design shown, the mechanical draft is attached to the boilers of the plant also, thereby extending its advantages to the power and light department, in addition to the utilization of the heat otherwise lost from the boiler furnaces. It is estimated that in this latter point alone is a sufficient saving to cover the cost of the operation of the mechanical draft equipment.

In the plan suggested, owing to the use of the producer gas, it becomes necessary to utilize a large amount of the heat from the cooling wares to obtain the proper combustion. Any heat from this source in addition to what is needed for combustion would be drawn forward and turned into the chambers ahead of the fire, thereby preparing them for contact with the combustion gases, without risk of any deposit of dew, which in ordinary continuous kiln practice frequently gives rise

to scumming. The gases of combustion after passing through as many chambers as was found economical would enter the smoke duct and pass on to the fan, and thence through the fan to the open air.

Kiln Capacity Required.—Owing to the variations in the rate at which different clays can be burned and cooled, it is impossible to furnish exact sizes of kiln chambers except by making arbitrary assumptions. Each kiln or chamber should hold a single day's output of the plant, and it will be assumed that the clay can be burned safely in seventy-two to eighty hours and that a chamber can be cooled in the succeeding forty-eight hours. Then to care for the output of the plant as already listed, the chambers should be approximately fourteen feet by eighteen feet in the clear, not counting bag space. A chamber of this size, where kiln blocks are used for the setting, would hold approximately nine thousand five hundred Spanish tiles, or one day's run less the dryer loss and setting breakage. Thus to care for the Spanish tiles it would need three such chambers per week, each alternating with a chamber for interlocking tiles. The same sized chamber would hold a two days' run of interlocking tiles. With the pentagon press operating six days of each week, three chambers would be needed to hold the weekly interlocking tile output.

In order to care for the special work from the trimmings press, hand press, and terra cotta room, it would be necessary to provide two more chambers. While the last two chambers would not be used exclusively for the special ware, their capacity would be needed to provide for the crowding out of the regular tiles by the trimmings or terra cotta set in each chamber from day to day. The burning cycle for each kiln would be: setting, one day; burning, three to three and one-half days; drawing, one day; total, seven to eight days. But to allow for the irregularities introduced by Sundays and holidays, and the exigencies of labor shortages, unfavorable weather, cleaning and repairs, etc., at least one extra day should be allowed per cycle in computing the monthly kiln schedule, and this would call for at least nine kilns for the plant.

The necessary equipment for each burning would include fire clay kiln blocks or supports sufficient to equip each kiln. For the chambers in which the Spanish tiles are set, there would be required two thousand blocks two and one-half by eleven by fifteen inches. The chambers to be used for interlocking tiles would need approximately twelve hundred blocks two and one-half by eleven by eleven inches and eleven hundred blocks two and one-half by eleven by fifteen inches.

The shingle tiles would be set with straps, as described in Chapter VII, and could therefore use the same blocks and chambers as used for the Spanish tiles.

Power Plant.—The power required for the machinery in the plant just described would amount approximately to 130 horse power. Hence,

in order to allow for the addition of a second auger machine and several pentagon presses, it would be advisable to install a 200 horse power engine in the beginning. This engine should be of Corliss or equivalent grade and of high efficiency.

The steam necessary to operate the plant could be furnished by two 150 horse power boilers of the tubular type, but there should be installed a third boiler, in order that one boiler could be shut down for cleaning and necessary repairs at any time. Steam for the two fan engines would also have to be furnished from the boiler plant.

The exhaust from the four engines and two pumps would partly be passed through a feed-water heater and, with the remainder not so needed, would then be sent to the steam coils which would be a part of the equipment for the heater for the dryer.

In addition to the regular power there would be installed a 50 horse power engine for driving a dynamo, to furnish light and power for distant machinery, such as pumps, glaze mills, or machine shop tools. The dynamo would be so located that in case of the breakdown of the small engine, a belt drive could be used from the main line shaft as indicated.

The coal necessary for the boilers would be delivered on a railroad spur passing the boiler room, and would then have to be shoveled into the coal storage bins behind the boilers.

For general shop work and repairs about the plant a room has been set aside in the boiler room (marked machine shop). In this room there would be a drill press, lathe, shaper, emery wheels, small forge and blacksmith tools, tools for pipe work, etc., with storage room for chain hoists, jack screws, bars and other tools essential about a plant of this nature.

Future Expansion of the Plant.—That the plant has been so designed as to be very easily enlarged can be readily seen.

In the power department space has been left for a fourth boiler and an engine has been installed of greater capacity than will be needed at the first. In the clay-preparing department the rolls, disintegrator and pug mill originally installed will care for twice the initial output. As it became necessary to increase the manufacturing capacity with more pentagon presses, the terra cotta room, its dryer and the plaster room could be moved back far enough to allow for the additional presses. The end of the building in which the terra cotta room is located would be of temporary construction, so that the extension of the building would be a simple problem.

The position of the trimmings press could then be changed further back, so that the regular presses could be located properly. The dryer could be extended by the addition of as many tunnels as necessary, without any change whatever except the moving over of the return

car track on that side of the dryer. The fans and ducts for both mechanical draft and the dryer would be installed sufficiently large to care for any reasonable growth.

The enlargement of the kiln capacity would require only the building of more chambers onto the end of the original kiln.

The fuel gas plant would consist of two producers, only one of which would be required at a time, the additional one being held in reserve in case of trouble with the one under fire. Hence, in case of the number of kiln chambers being increased, both producers could be put into commission and a third one built for emergencies. The loading switch could very easily be extended to care for the increased output.

Figure 188, inserted to face this page, is a design for the ground plan of the hypothetical Roofing Tile plant, which serves as the basis of the discussion on plant design, page 981–990. The kiln plant is necessarily much shortened to get it within the available space. The scale of the drawing, after reproduction by the engraver, is approximately 17.2 feet per inch.

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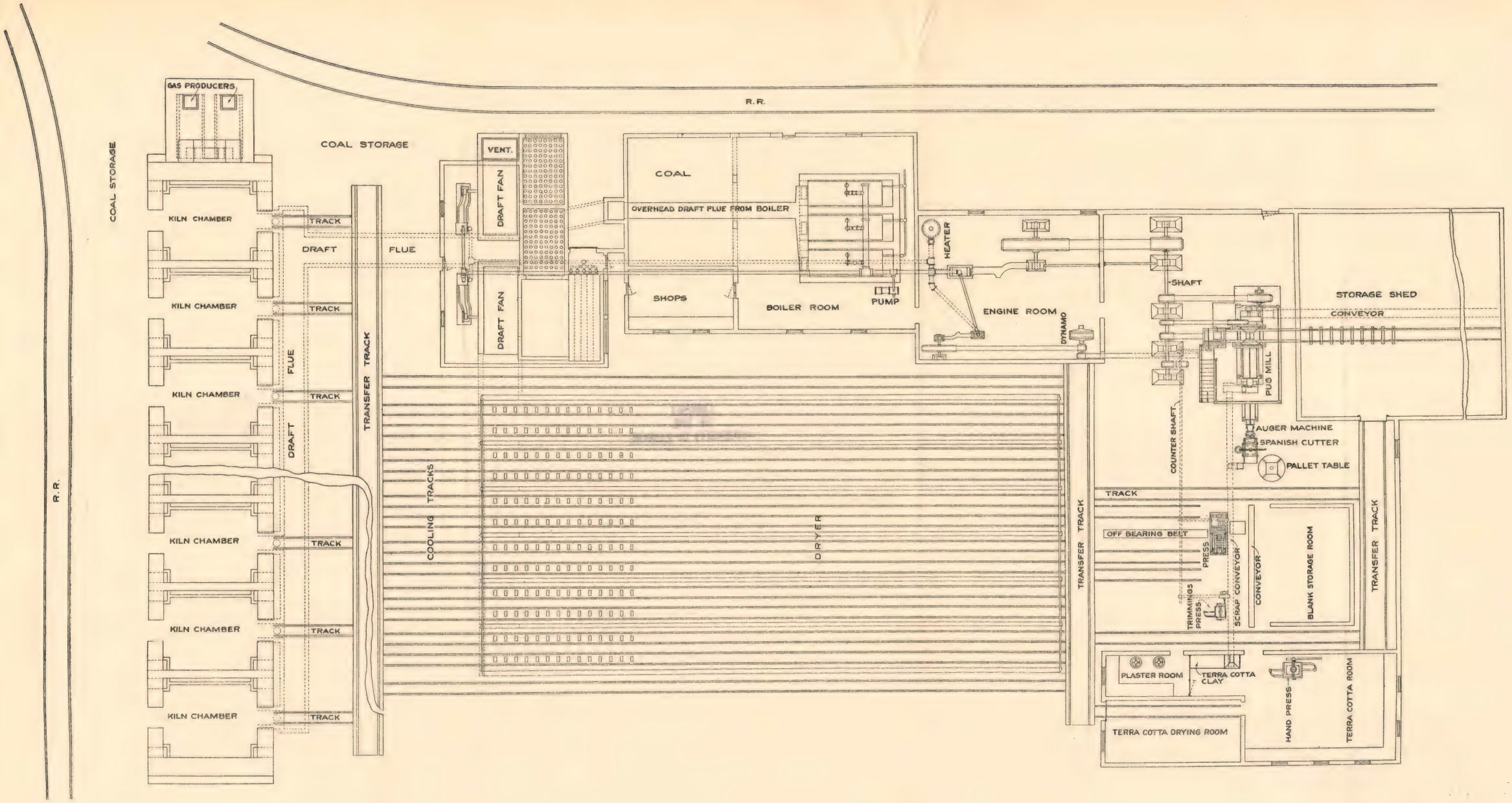
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PALLET TABLE
COOLING TRACKS
DRYER
OFF BEARING BELT
PRESS
TRIMMINGS PRESS
SCRAP CONVEYOR
BLANK STORAGE ROOM
PLASTER ROOM
TERRA COTTA CLAY
HAND PRESS
TERRA COTTA ROOM
TERRA COTTA DRYING ROOM

Geological Survey of Ohio, Bulletin Eleven. Figure 187.
Ground Plan Design for a Roofing Tile Plant.

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